MARCH 1959

JOURNAL OF THE IRON AND STEEL INSTITUTE

4 GROSVENOR GARDENS · LONDON SWI

Established 1869 · Incorporated by Royal Charter 1899

VOL. 191 PART 3

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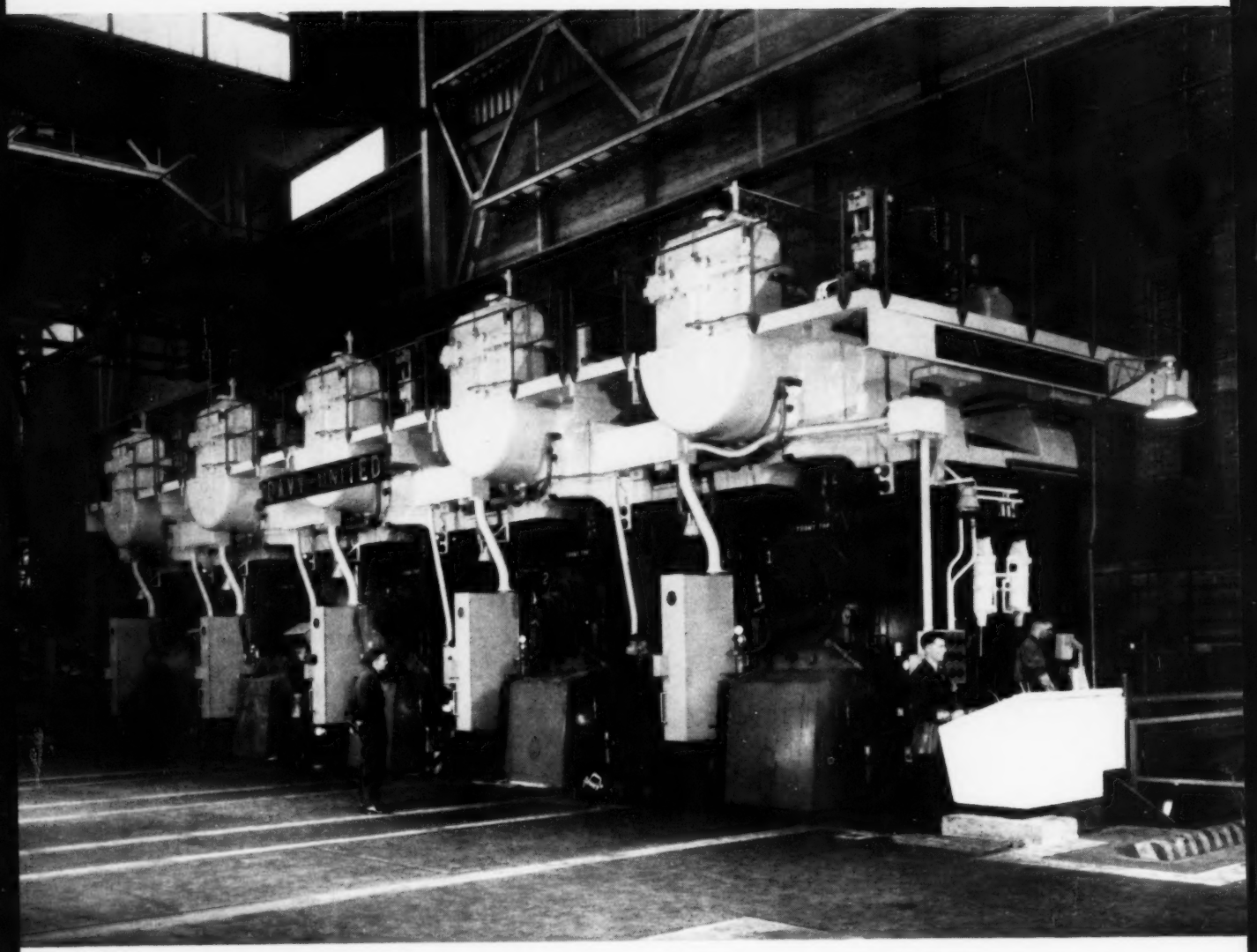
more strip for **TINPLATE**



The 21″ and 53″ × 42″ 5-Stand Tandem Cold Strip Mill at Velindre, rolling steel strip for tinplate at 5,000 feet per minute.

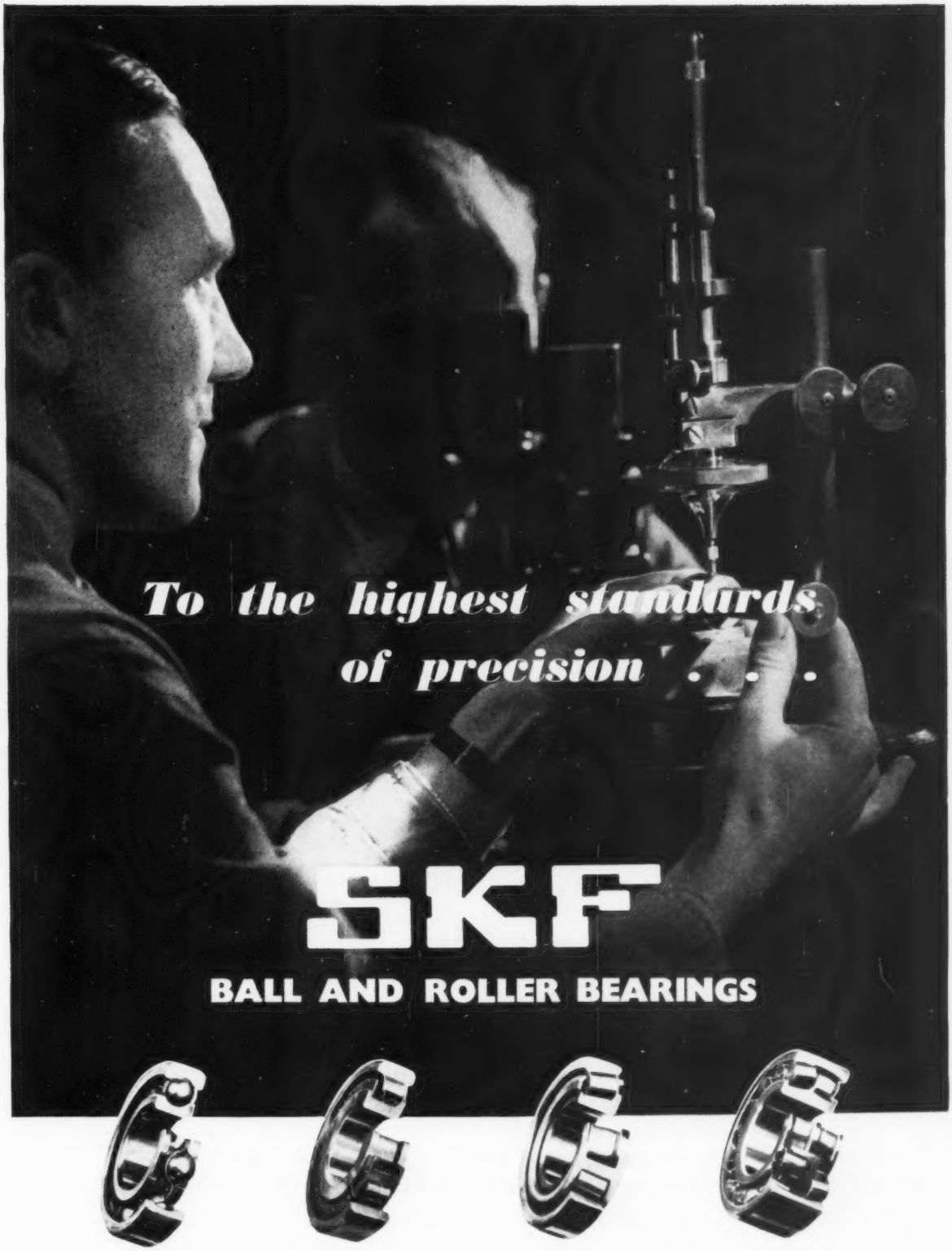
"The Velindre Tinplate Mill of the Steel Company of Wales is the most modern in the world and has come into operation more quickly and smoothly than was to have been anticipated."

The Chairman, The Metal Box Company Limited, in Statement to Shareholders 21st July, 1958.

DAVY-UNITED

SHEFFIELD · MIDDLESBROUGH · GLASGOW

287/D.U.



THE SKEFKO BALL BEARING COMPANY LIMITED · LUTON · BEDS

THE ONLY BRITISH MANUFACTURER OF ALL FOUR BASIC BEARING TYPES: BALL, CYLINDRICAL ROLLER, TAPER ROLLER & SPHERICAL ROLLER

March, 1959

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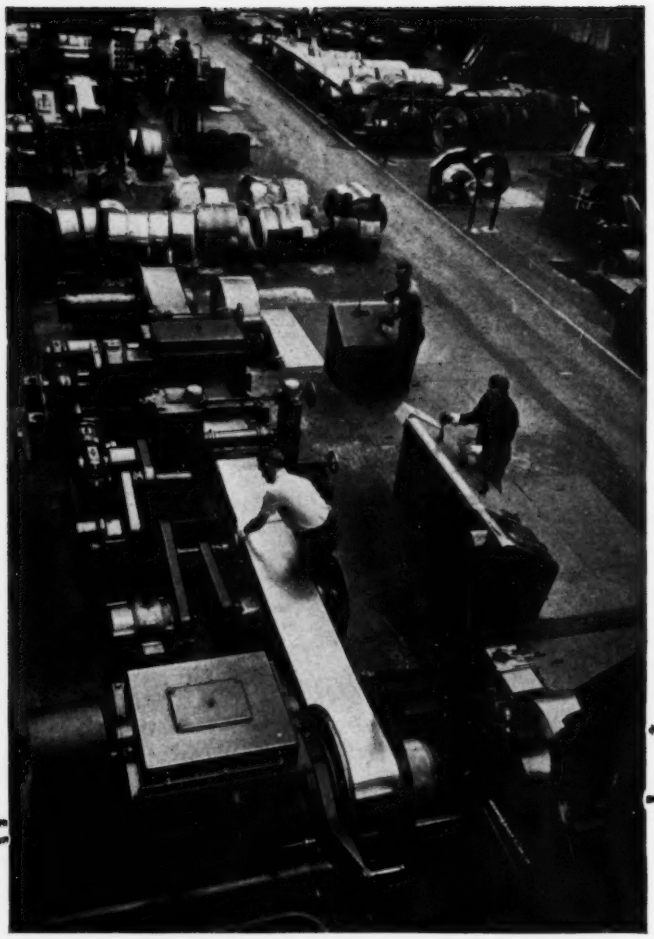


This complete BIGWOOD slitting line operates in the Castle Works of Guest Keen & Nettlefolds (South Wales) Ltd

BIGWOOD

The complete Bigwood slitting line shown above comprises coil loading bogie, pay-off reel, oiling machine, gang slitter, re-coiler with hydraulic push-off and coil stripper carriage.

The line can deal with strip up to a maximum width of 20 inches in thicknesses from 0.04 to 0.064 ins. at a pass speed of 250/450 ft. per minute.

JOSHUA BIGWOOD & SON LIMITED · WOLVERHAMPTON

MAKERS OF: Straightening Machines (for bars, tubes & sections), Roller levellers, Hydraulic stretchers, Plate & section benders, Screw presses, Coil processing lines, Lines for forming sections from strip, and a variety of other metal working machines.

B.142

WASTE HEAT RECOVERY

Ore and limestone handling at Ravenscraig

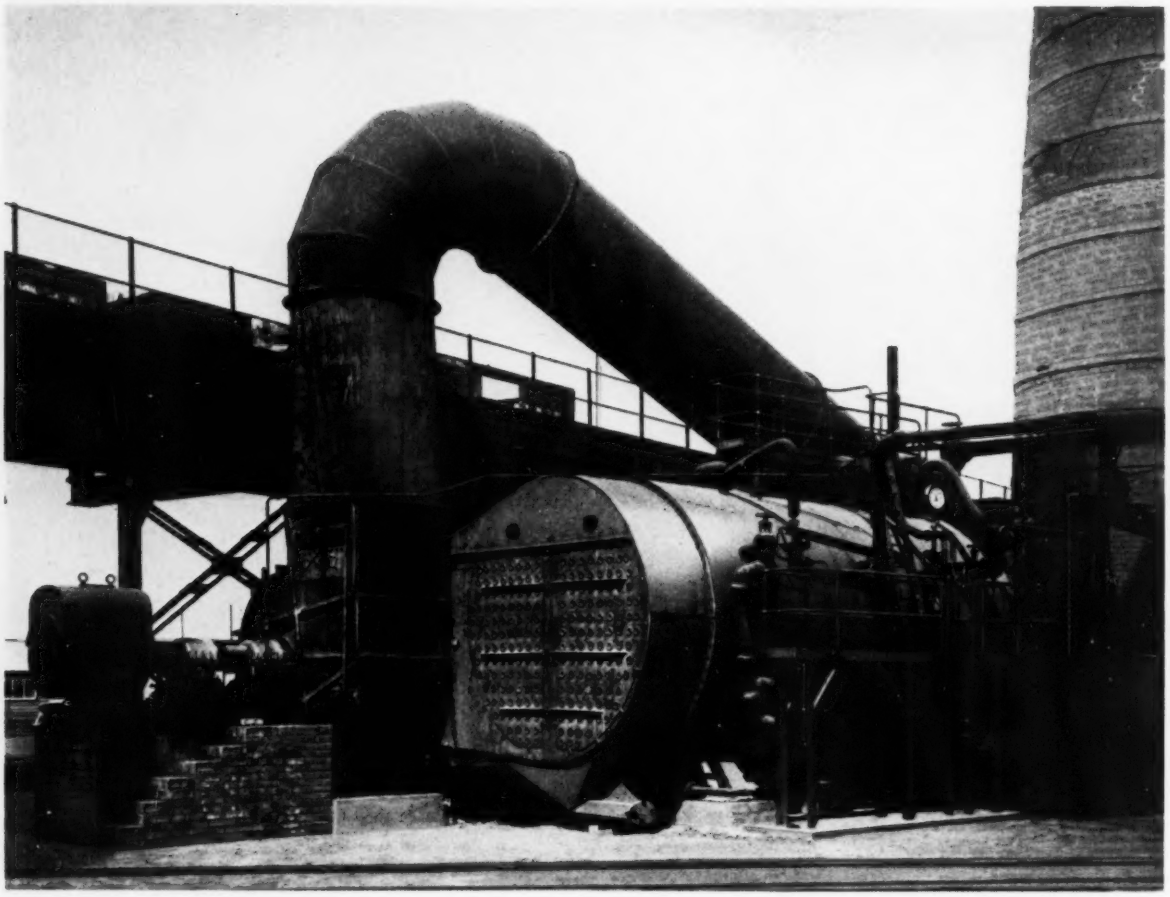
Equipment installed includes

WAGON TIPPLER
DUST TRAPPING
BELT CONVEYORS
TELPHER SYSTEM
WAGON MARSHALLING
AUTOMATIC BATCHING

STRACHAN & HENSHAW LTD

STEELHOIST WORKS, BRISTOL. TELEPHONE 78331

WASTE HEAT RECOVERY IN THE STEEL INDUSTRY



Photograph by courtesy of Messrs. John Lysaght's Scunthorpe Works Ltd.

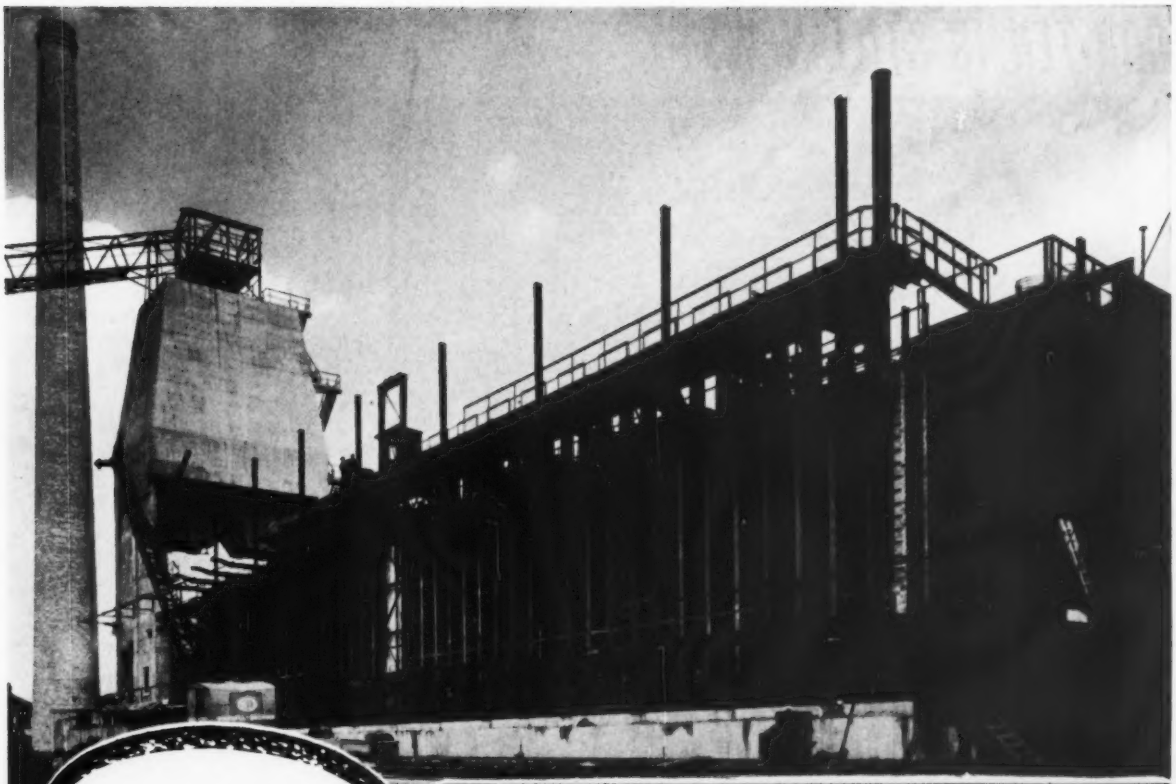
One of a battery of SPENCER-BONECOURT Waste Heat Boilers operating on Open Hearth Steel Melting Furnaces at John Lysaght's Scunthorpe Works Ltd., Scunthorpe.

Waste heat recovery on Steel Melting Furnaces is essential to increase thermal efficiency, and is also a proved means of increasing steel output to assist in satisfying the ever-widening demand.

Consult the Specialists in Waste Heat Recovery

SPENCER-BONECOURT-CLARKSON LTD

28 EASTON STREET, LONDON, W.C.1 Telephone: TERminus 7466. Telegrams: "Heatecon, Phone, London".



GLASSHOUGHTON
FIRST INSTALLATION
42 OVENS

NEW coking plants under construction

APPLEBY-FRODINGHAM
SECOND INSTALLATION
66 OVENS

CORBY-DEENE
FIRST INSTALLATION
51 OVENS

Operating Nov. 1958
MURTON
FIRST INSTALLATION
50 OVENS

Operating July 1958
PRETORIA
SIXTH INSTALLATION
51 OVENS

VANDERBIJL PARK
THIRD INSTALLATION
55 OVENS

BAIRDS
SECOND INSTALLATION
37 OVENS

LYSAGHT
FIFTH INSTALLATION
23 OVENS

PRETORIA
FIFTH INSTALLATION
51 OVENS

REDBOURN
THIRD INSTALLATION
62 OVENS

The New Batteries of W-D Becker Underjet Coke Ovens at the Glasshoughton Works of the North Eastern Division of the National Coal Board nearing completion.
The Batteries will carbonise some 880 tons of coal daily from which blast furnace, domestic and industrial coke and town gas will be produced.

WOODALL—DUCKHAM
Construction Company Ltd.

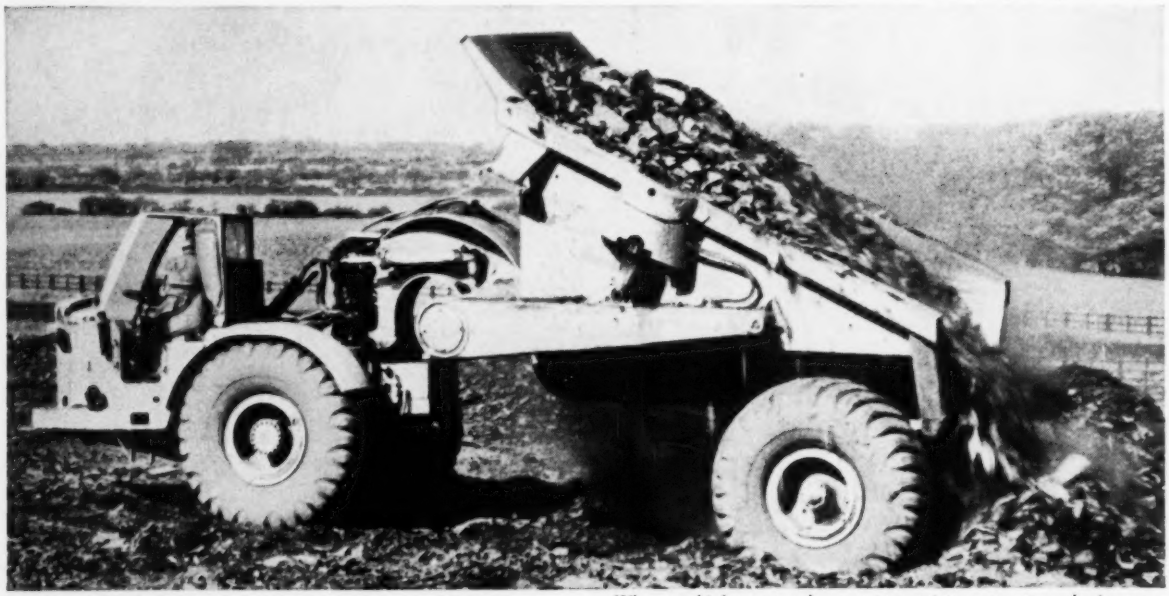
Woodall-Duckham House, 63-77 Brompton Road, London, S.W.3. Tel: KENsington 6355 (14 lines) Grams: Retortical (Southkens) London

COR-TEN IS STILL NEWS

In 1954, for the first time in Britain on a wide continuous strip mill, The Steel Company of Wales began the manufacture of SCW Cor-Ten.

Today, four years later, the range of application for SCW Cor-Ten continues to grow as more designers and more users discover new ways in which they can take advantage of its outstanding properties.

Photograph by courtesy of Caterpillar Tractor Company Ltd.



Wherever higher strength or greater resistance to atmospheric corrosion offer economic advantages, SCW Cor-Ten *has been used. Where corrosion and abrasion are both present (as in the case above)* SCW Cor-Ten's *outstanding advantages are particularly effective.*

COR-TEN IS TOUGHER

- Weight for weight, the yield strength of SCW Cor-Ten is 50% higher than ordinary mild steel
  alternatively
  Strength for strength, a saving of $\frac{1}{3}$ of the weight is possible
- 4-6 times more resistant to atmospheric corrosion
- Highly resistant to abrasion and fatigue.

COR-TEN SAVES MONEY

- Initial costs are spread over a longer service life
- Maintenance costs are reduced
- Operating costs are lowered—in transport applications payloads are bigger because of reduction in tare weight

Please write to us at the address below for further information or for technical assistance in the application of SCW Cor-Ten *to your products*

S·C·W BRAND Cor-Ten

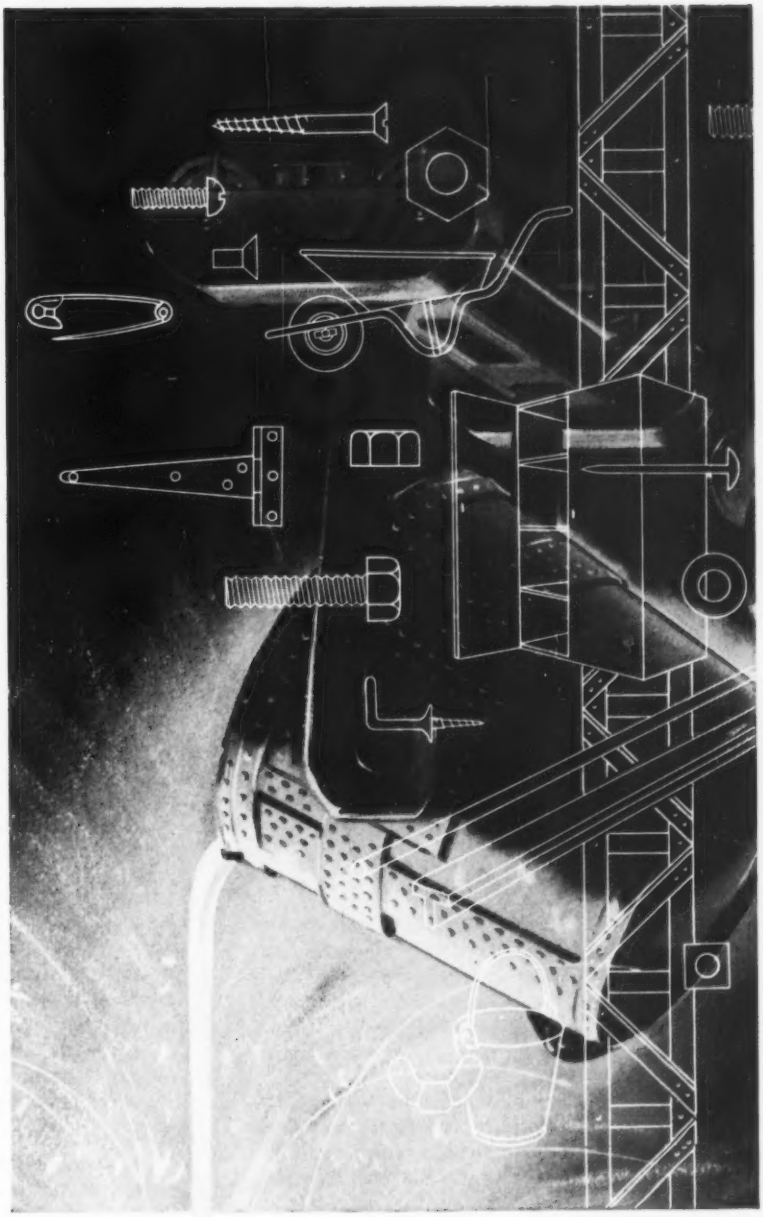
RAILWAY ROLLING STOCK
AGRICULTURAL AND EARTH-MOVING EQUIPMENT
MINE CARS · POWER STATION INSTALLATIONS
BARGES AND SMALL CRAFT

THE STEEL COMPANY OF WALES LIMITED

ABBEY WORKS, PORT TALBOT, GLAMORGAN TELEPHONE: PORT TALBOT 3161

GKN

put steel into shape



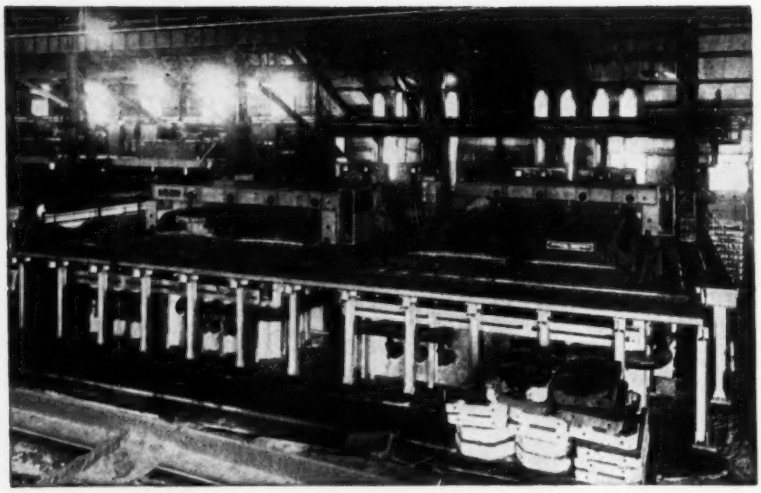
Wherever you go you will find the products of one or another of the companies in the GKN group. From safety pins to steel furniture, buckets to bridges, light pressings to giant stampings, the smallest screw to the largest steel buildings—GKN make something for every industry under the sun. Whatever may be needed in the way of steel components or assemblies, there's a GKN company with the experience, the resources and the big-scale production facilities to supply it.

For steel in any shape or form you'll find GKN a handy group to know

GKN products and services include: INDUSTRIAL STEEL; RAILWAY, COLLIERY AND FARMING EQUIPMENT; WHEELS AND CHASSIS FRAMES; SCAFFOLDING AND RAINWATER GOODS; WELDED PIPEWORK; HOLLOWARE; FORGINGS AND PRESSINGS; COMPLETE ASSEMBLIES OF ALL KINDS; FASTENINGS FOR EVERY PURPOSE.

GUEST, KEEN & NETTLEFOLDS, LIMITED, 66 CANNON STREET, LONDON, E.C.4.

ISLEY CONTROLLED



(1) 14-hole Soaking Pit Installation in South Wales fired with cold blast furnace gas and having accommodation for 140 four-ton ingots.

Repeat order for 4-holes with fully automatic reversing control now in operation, making total capacity 180 four-ton ingots.

Further repeat order for 4-holes now in operation with complete fully automatic reversing equipment together with fully automatic air/gas ratio and draught control, and completely sealed covers, making a total holding capacity of 220 4-ton ingots.

(2) Installation in Cumberland accommodating 40 four-ton ingots and fired with blast furnace and coke oven gas having no pre-heat. Automatic gas/air ratio control.

(3) Installation in India with 16-holes fired with cold blast furnace gas and having automatic reversing control.

(4) Installation on N.E. Coast accommodating an average of 100 tons of slab ingots varying between 4 and 11 tons each, fired with 100 per cent. cold blast furnace gas, with fully automatic reversal.

(5) Installation on N.E. Coast accommodating 160 3½/4-ton ingots, fired with blast furnace gas and having fully automatic reversal equipment and air/gas ratio control.

(6) Installation in the Midlands of 4-hole plant accommodating 40 3/3½-ton ingots fired with 100 per cent. cold blast furnace gas with automatic reversal equipment, gas/air ratio and furnace pressure control with completely sealed covers.

Repeat order for 2-hole plant to accommodate 24 3/3½-ton ingots with fully automatic reversing equipment and complete automatic air/gas ratio and draught control with completely sealed covers.

(7) Installation in South Africa of 8-holes with automatic reversal and fully automatic combustion control now under construction.

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56 KINGSWAY, LONDON, W.C.2

SOAKING PIT FURNACES

★ PERFECTLY UNIFORM HEATING BOTTOM AND TOP OF INGOT.

★ EXTREMELY SIMPLE CONTROL.

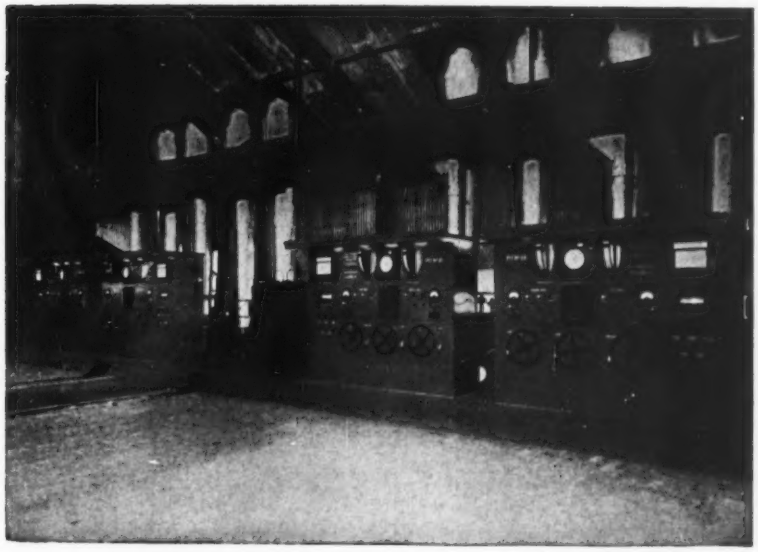
★ SUITABLE FOR FIRING WITH PRODUCER, BLAST FURNACE OR MIXED GAS.

★ ISLEY SOAKING PITS WILL HEAT COLD INGOTS TO OVER 1300° C. USING STRAIGHT BLAST FURNACE GAS WITH ABSOLUTELY NO PREHEAT OF GAS.

★ COMPLETELY SEALED COVERS.

★ AUTOMATIC GAS/AIR RATIO CONTROL AND AUTOMATIC FURNACE PRESSURE CONTROL.

★ FULLY AUTOMATIC REVERSAL GEAR.

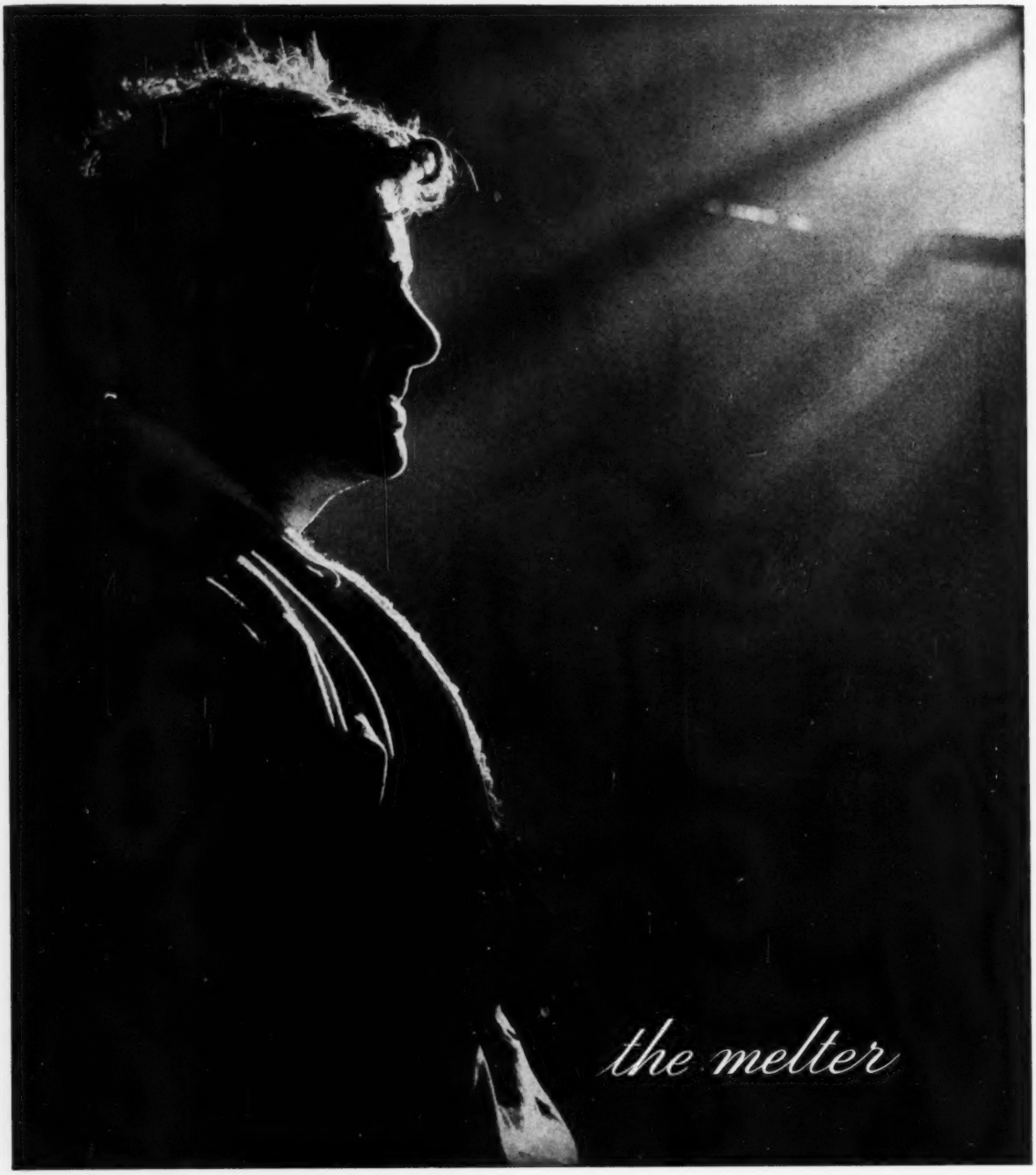


OTHER SPECIALITIES:

PRODUCER GAS MACHINES ● HOT METAL MIXER CARS ● TYPHOON ROTARY FLAME GAS BURNERS ● MILL FURNACES ● "ARCA" GAS PRESSURE REGULATORS ● AIRJECTORS ● NASSHEUER CONTINUOUS BRIGHT ANNEALING FURNACES (SOLE LICENSEES)

CONSTRUCTION CO. LTD.

Telephone: HOLBORN 1871/2 Telegrams: SAHLIN, WESTCENT 2 LONDON



BROWN BAYLEY
STEELS LIMITED
SHEFFIELD

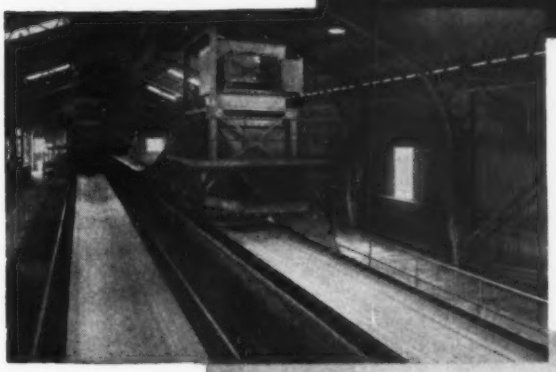
BROWN
BAYLEYS

MOXEY

DESIGN, MANUFACTURE AND INSTALL

Conveyors Feeding Iron Ore to Blast Furnace Bunkers.

Ore Plants
Fuel Plants
Bulk Handling
Belt Conveyors
Belt Conveyor Idlers
Slat Conveyors
Scraper Conveyors
Chain Conveyors
Portable Conveyors
Roller Conveyors
Bucket Elevators
Swing Tray Elevators
Skip Hoists
Vibrating Screens



Trippers feeding Ore to Dockside Bunkers.

Boomstacker stock-piling Iron Ore.

MOXEY LTD

13 AUGUSTUS ROAD
BIRMINGHAM 15

Also at LONDON, GLASGOW, MONTREAL, MELBOURNE

Iron Ore Stocking out Bridge.

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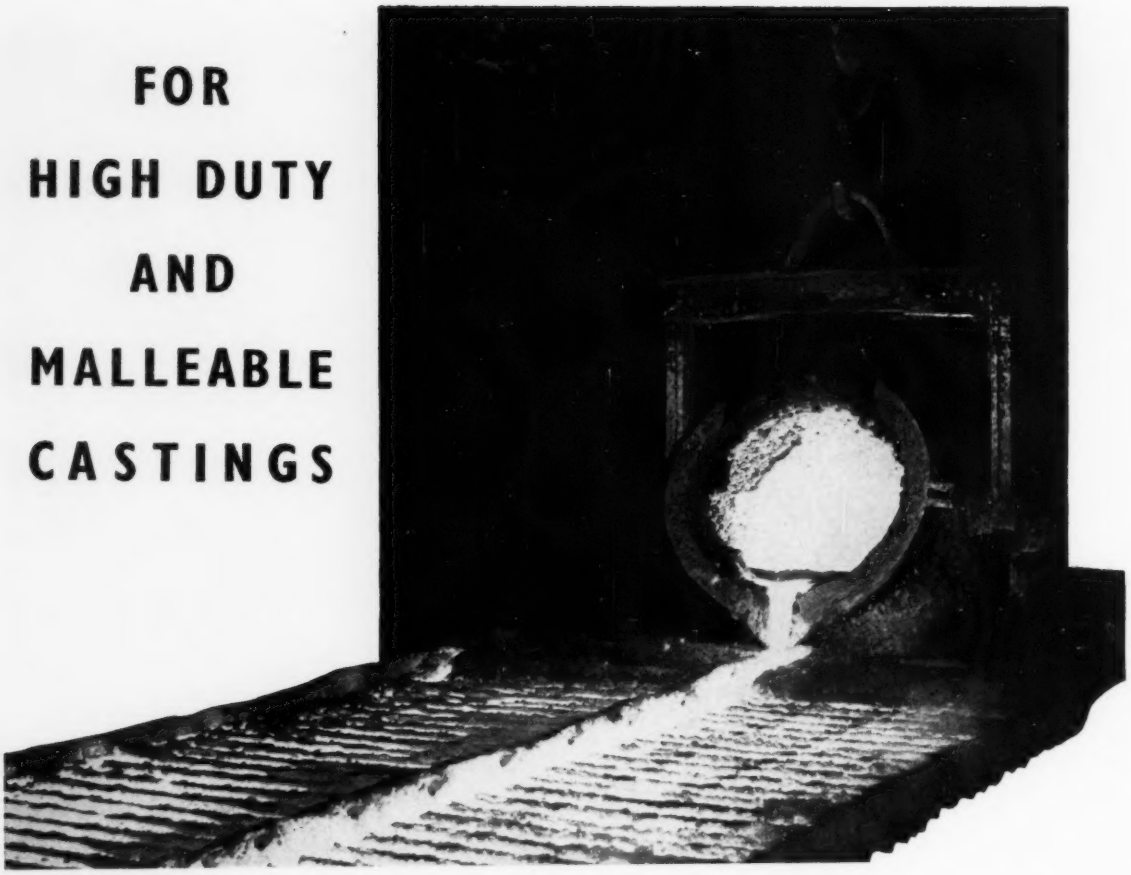
FOR HIGH DUTY AND MALLEABLE CASTINGS



The seven standard grades of Stanton Dale Refined Pig Iron

GRADES:	A	B	C	D	E	F	G
SILICON %	1·9–2·1	1·4–1·6	0·9–1·1	2·25–2·5	0·9–1·1	1·4–1·6	1·9–2·1
SULPHUR %	0·06	0·07	0·08	0·05	0·08	0·07	0·06
PHOSPHORUS %	0·6–0·7	0·6–0·7	0·6–0·7	0·4–0·5	0·25	0·25	0·25
MANGANESE %	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5
TOTAL CARBON %	2·7–3·0					2·8–3·1	

In addition to the above other grades of Dale Refined Iron can be supplied to meet more exacting demands which call for alloy additions and special processing.

STANTON *Dale Refined* PIG IRON

THE STANTON IRONWORKS COMPANY LIMITED NEAR NOTTINGHAM

*COWLES

COPPEE

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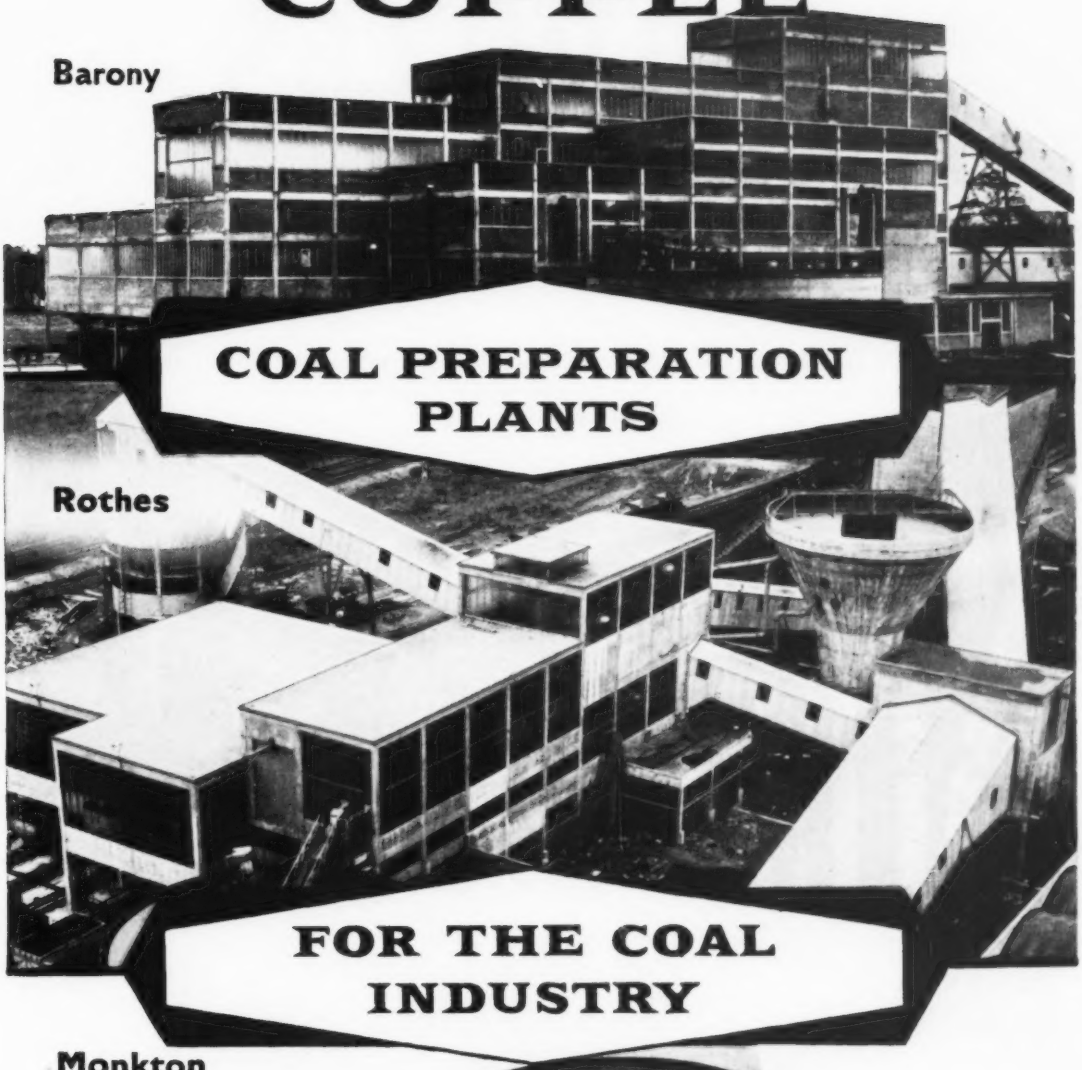
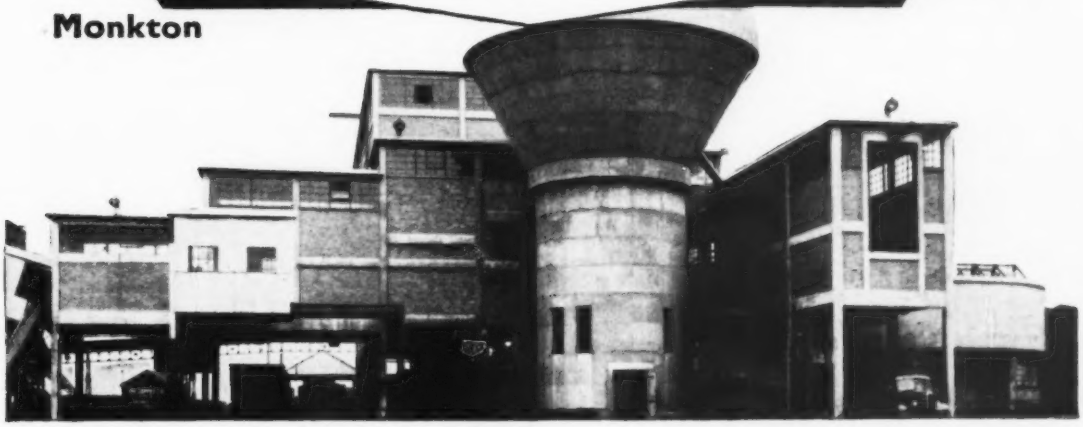


COAL PREPARATION PLANTS

Rothes

FOR THE COAL INDUSTRY

Monkton



Please write for further details to:

THE COPPEE COMPANY

COPPEE HOUSE · 140 PICCADILLY

LONDON W.1 Telephone: HYDe Park 6801

(GREAT BRITAIN) LIMITED

Telegrams: EVCOPPEE, NORPHONE, LONDON

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COLVILLES LIMITED

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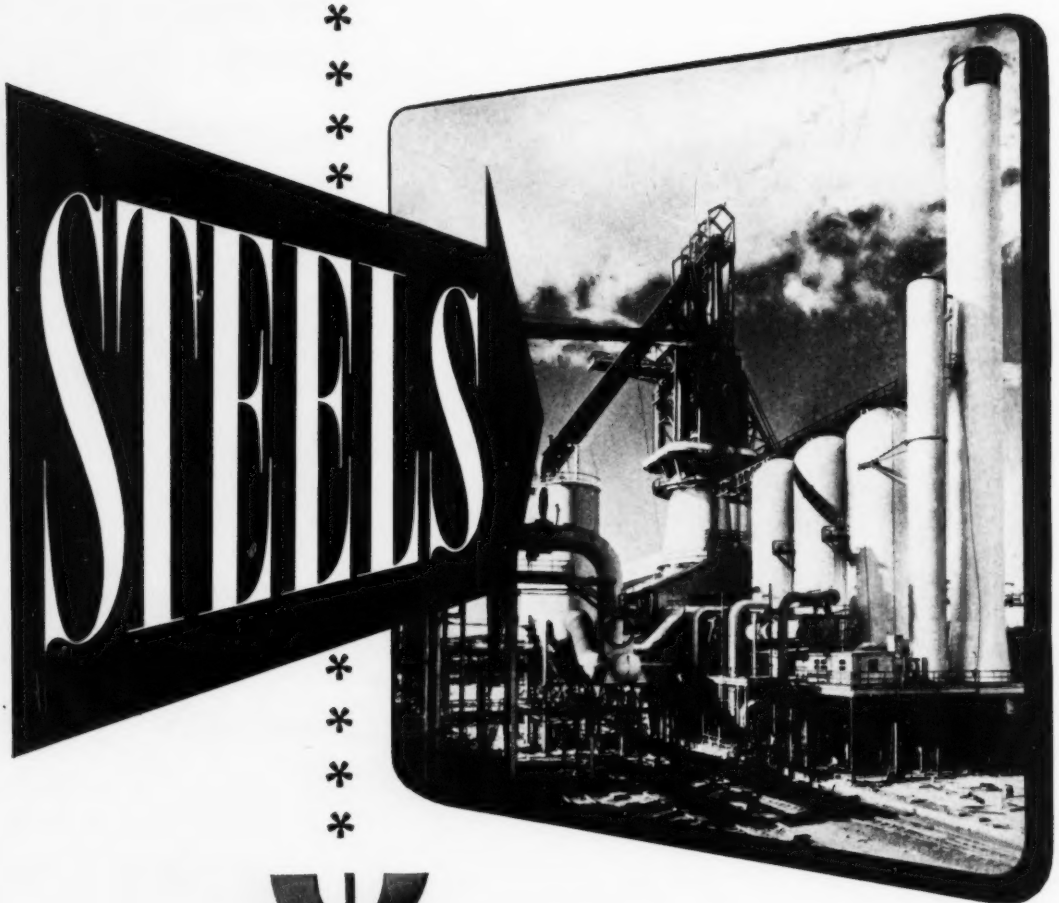

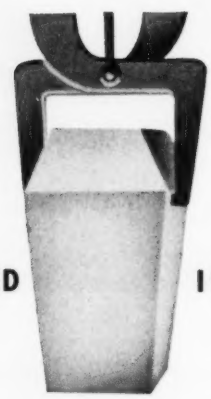

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Mobilux Grease is a lithium-base lubricant of excellent structural stability and purity. It is a new, general-purpose grease superseding conventional greases. It provides effective lubrication for the majority of grease applications over a temperature range from minus 20°F to 250°F. It is exceptionally resistant to water washing and contains special additives to prevent rust formation. Both in the laboratory and in the field Mobilux Grease has proved its outstanding efficiency as a lubricant and protector.

MOBILUX GREASE

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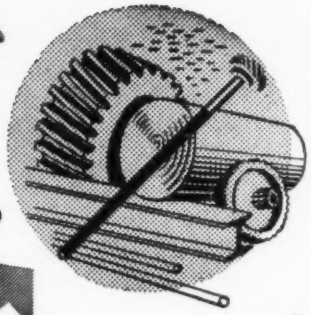
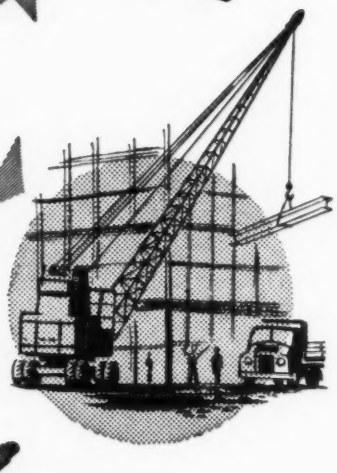
MOBIL INDUSTRIAL LUBRICANTS

Scrap clearance..



dismantling.....



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Scapa Works
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Oldbury, Birmingham
Tel: Broadwell 1611

MANCHESTER
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Salford 6
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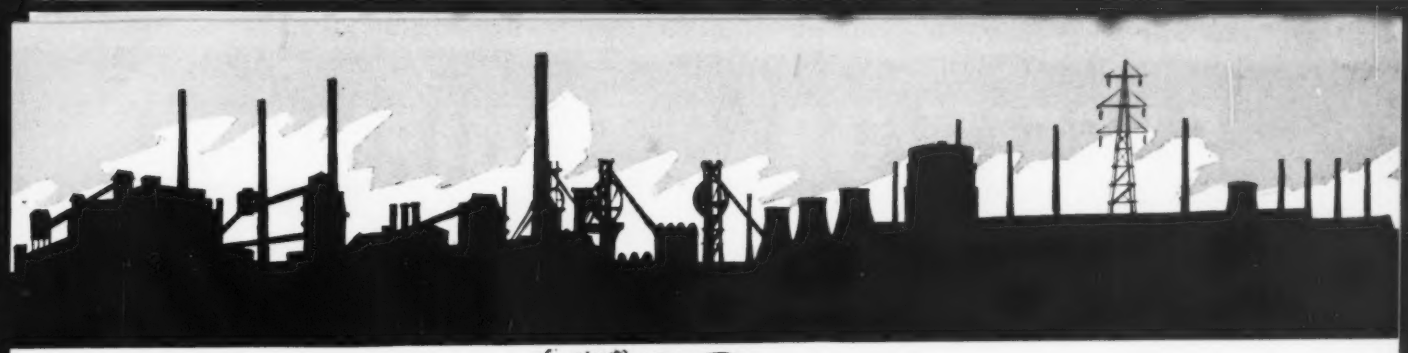
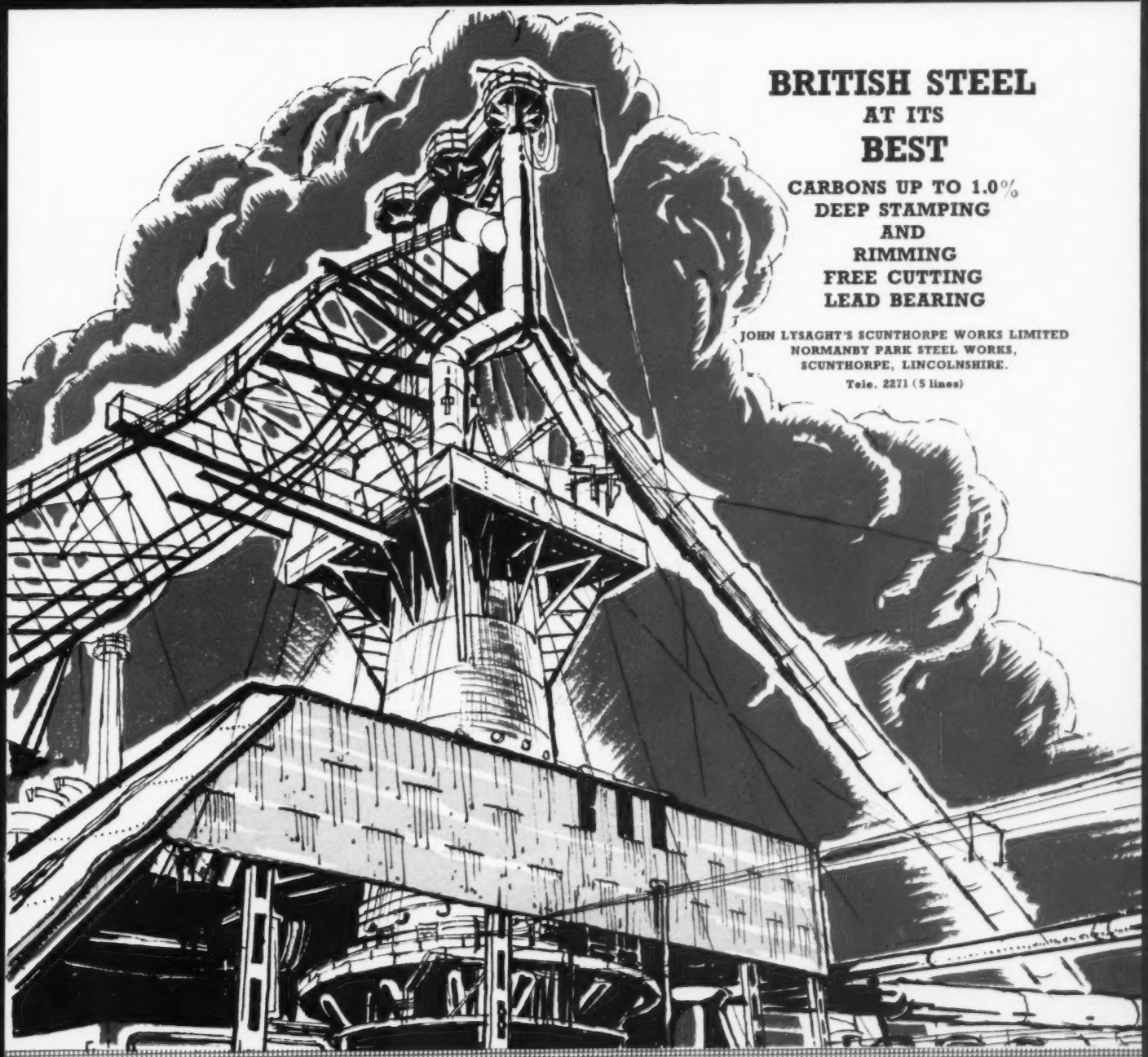
A METAL INDUSTRIES GROUP COMPANY

STEELWORKS EQUIPMENT





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AT ITS
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CARBONS UP TO 1.0%
DEEP STAMPING
AND
RIMMING
FREE CUTTING
LEAD BEARING

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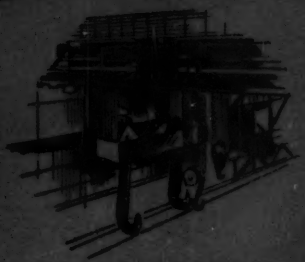
LYSAGHT'S SCUNTHORPE

STEELWORKS EQUIPMENT *by* ADAMSON-ALLIANCE



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SOAKING PIT CRANES

STRIPPING CRANES

CHARGING MACHINES

AA

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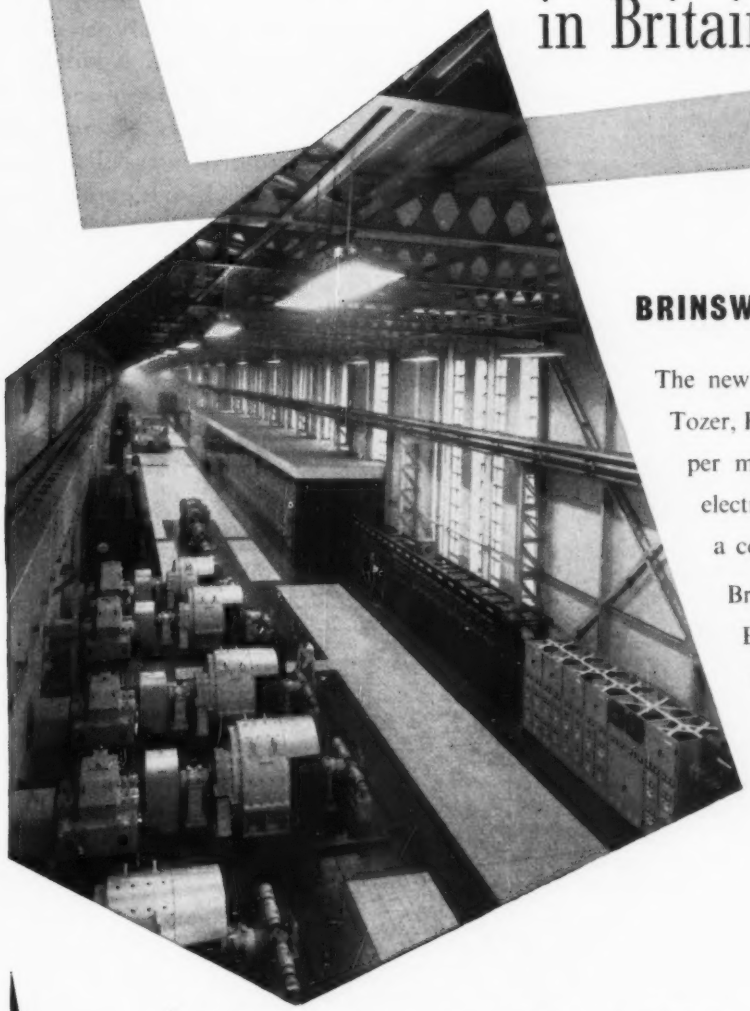
Incorporating the Steelworks Divisions of

JOSEPH ADAMSON & CO. LTD · HYDE · CHESHIRE

THE HORSEHAY CO. LTD · WELLINGTON · SALOP

Electrification of the fastest hot strip mill in Britain



BRINSWORTH MILL, ROTHERHAM

The new Brinsworth Mill of Steel Peech & Tozer, Rotherham, which produces 3,300 ft. per minute of hot strip was engineered electrically by 'ENGLISH ELECTRIC' under a comprehensive contract.

Brinsworth, the fastest hot strip mill in Britain, is powered by drives totalling over 14,000 h.p. r.m.s., fed from sealed steel tank mercury arc rectifier equipment.

The finishing stand controls incorporate automatic speed holding and automatic loop control.

'ENGLISH ELECTRIC'

steelworks equipment

THE ENGLISH ELECTRIC COMPANY LIMITED, MARCONI HOUSE, STRAND, LONDON, W.C.2

Metal Industries Division, Stafford

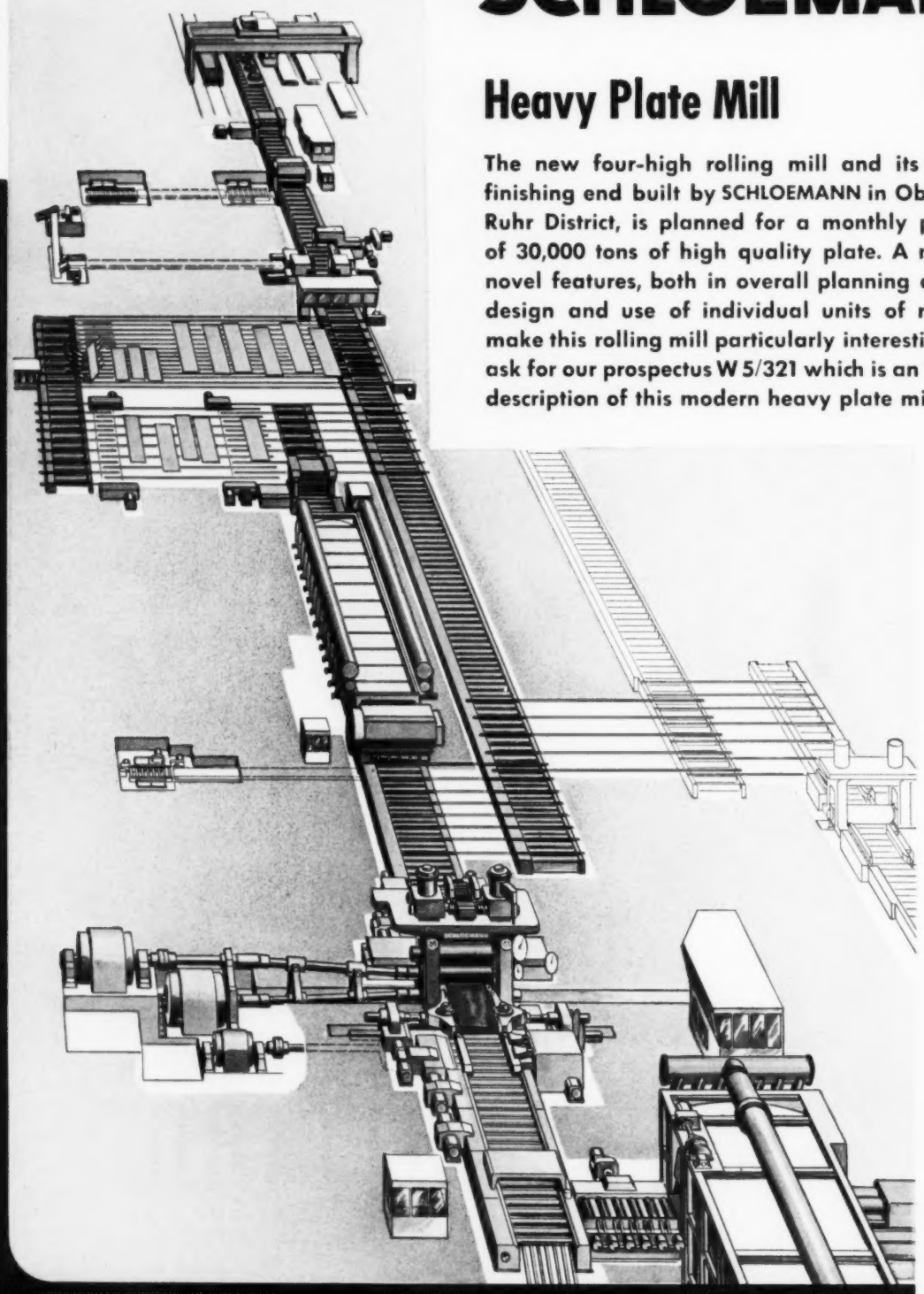
WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

MT48G8

SCHLOEMANN

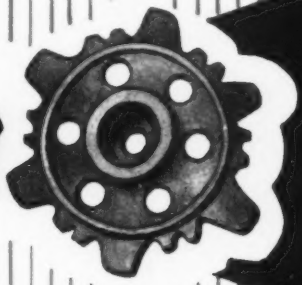
Heavy Plate Mill

The new four-high rolling mill and its extensive finishing end built by SCHLOEMANN in Oberhausen/ Ruhr District, is planned for a monthly production of 30,000 tons of high quality plate. A number of novel features, both in overall planning and in the design and use of individual units of machinery, make this rolling mill particularly interesting. Please ask for our prospectus W 5/321 which is an illustrated description of this modern heavy plate mill.



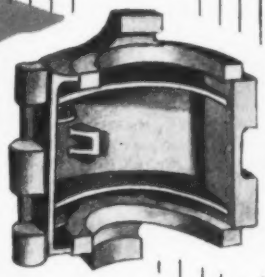
DOLLERY & PALMER LTD · 54, Victoria Street LONDON SW 1 · Lydgate Lane SHEFFIELD 10

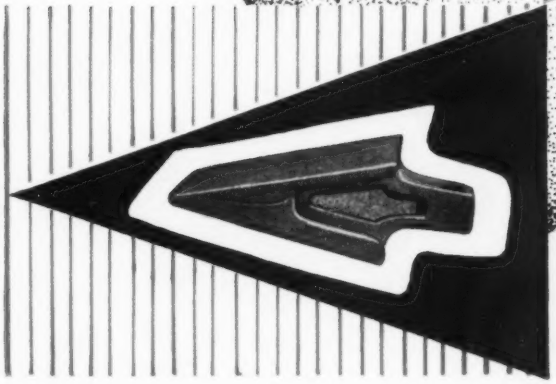
REPETITION



STEEL

CASTINGS





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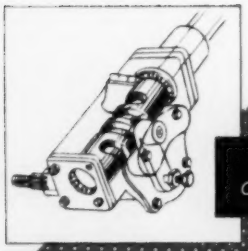
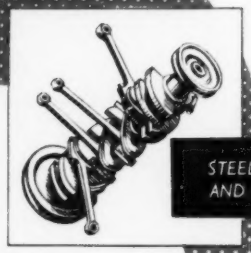
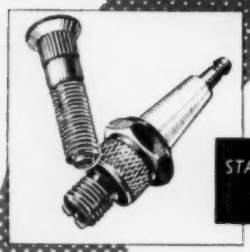


MILD, CARBON AND CASE-HARDENING STEELS



STEELS FOR FORGINGS AND DROP STAMPINGS



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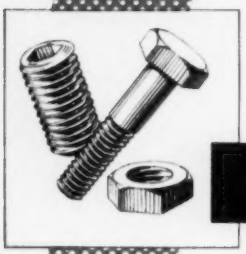
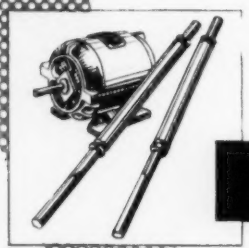
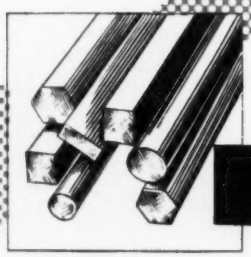
PARK GATE STEELS



COLD HEADING WIRE



HARD SHAFT STEELS



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Steels in the carbon range 0·08—0·85%
Case – Hardening Steels
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RANGE OF PRODUCTS

Billets from 3″ square upwards
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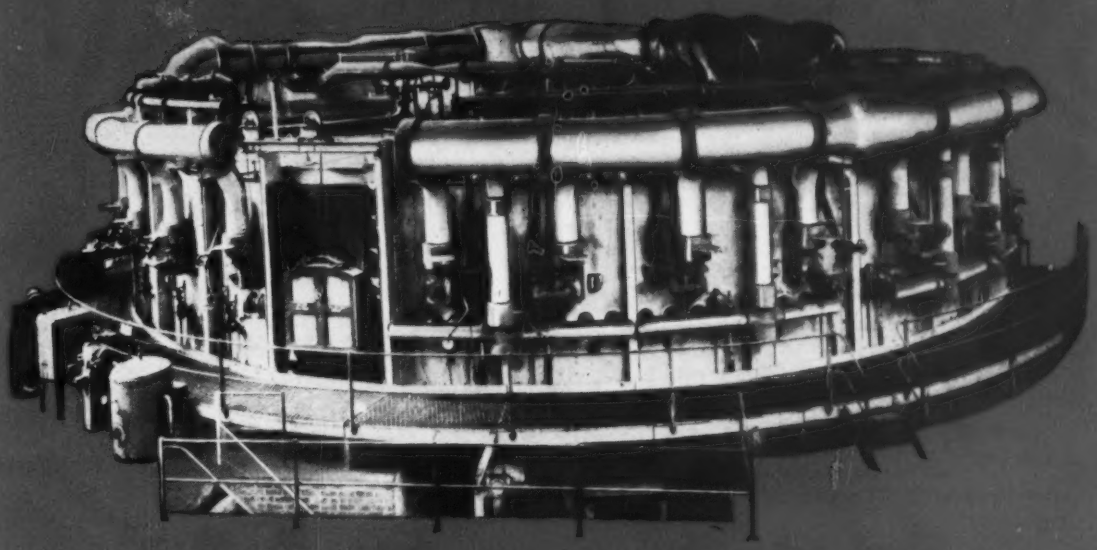
automatic charge and discharge



slabs up to 4½ tons weight and 70 tons per hour output

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show significant advantages over pusher-types.
They are complete with automatic charge and discharge equipment and handle Ingots, Slabs, Billets, or Rounds with a wide range of capacities. Economy of operation is achieved by reduced manpower, low maintenance and greater uniformity of heating. Each piece to be heated is placed separately on the hearth so that no cold spots are possible.

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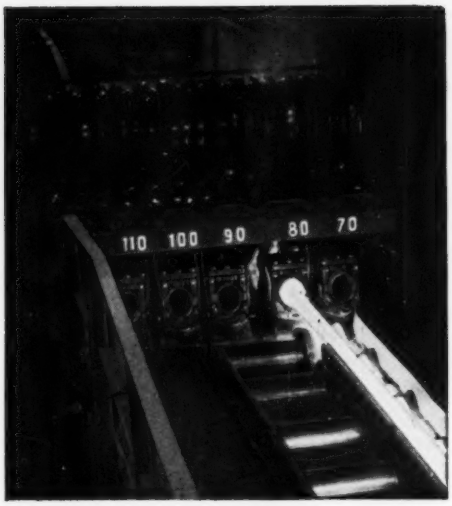
8 good reasons why you should use these ROLLER GUIDES in your bar or wire rod mill



Nos. 125 and 155 roller guides fitted in a 27 1/2 in. (700 mm.) diameter, three-high stand for rolling 2 3/4, 3 3/16, 3 9/16, 4, 4 3/8 and 4 7/8 in. (70, 80, 90, 100, 110 and 124 mm.).

1 The entry friction guides are rigidly clamped into the guide box. They are intended to lead the oval to the groove in the roller, to protect the rollers against overloading, and to straighten bent rods.
The groove in the entry guides is made about 1/8" wider than the oval.

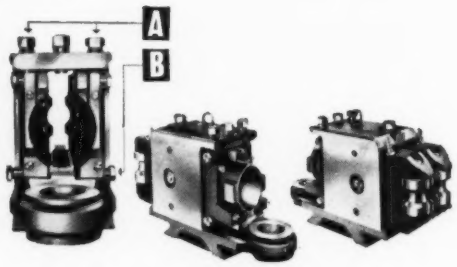
2 The rollers are mounted on leaf springs, which can be adjusted by means of the screws "B", and hold the oval steadily even if there should be some slight variation in the thickness of the oval.

3 If the thickness of the oval should vary, the springs of both rollers yield an equal amount, so that the oval remains in the centre of the groove.

4 To tilt the oval, the screws "A" are adjusted. One roller will then be lifted as much as the other is lowered.

5 As the oval is held very rigidly, the leader oval for wire rod may be thick, unless other circumstances call for a thinner oval.

6 The roller guide assemblies are narrow, and all screws that require adjustment during rolling are accessible from the front of the mill. No lateral space outside the guide box is therefore required for gaining access to the set screws, and the guide box assembly can thus be located close to the mill housing.



7 As the groove in the entry guides is wide and nothing but rolling friction acts on the oval, the latter is very easily introduced into the pass, and there is practically no risk of scratching the bar.

8 The roller guide may be used not only for leader and drawing oval passes but also for edging flats as well as for rolling squares, hexagons, octagons and various other sections, for instance in reduction passes for hexagon. It is suitable for all types of rolling mill. An important advantage is that the roller guide enables repeaters to be used in rolling plump leader-ovals.

PS *Practically speaking, every bar and wire rod mill in Scandinavia uses roller guides of our design.*

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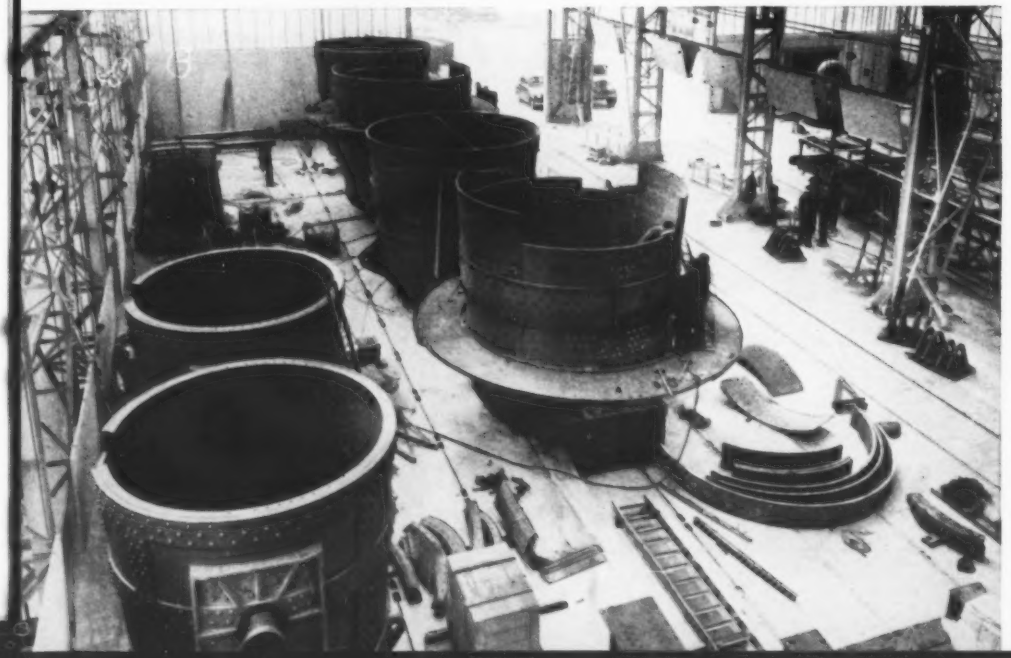
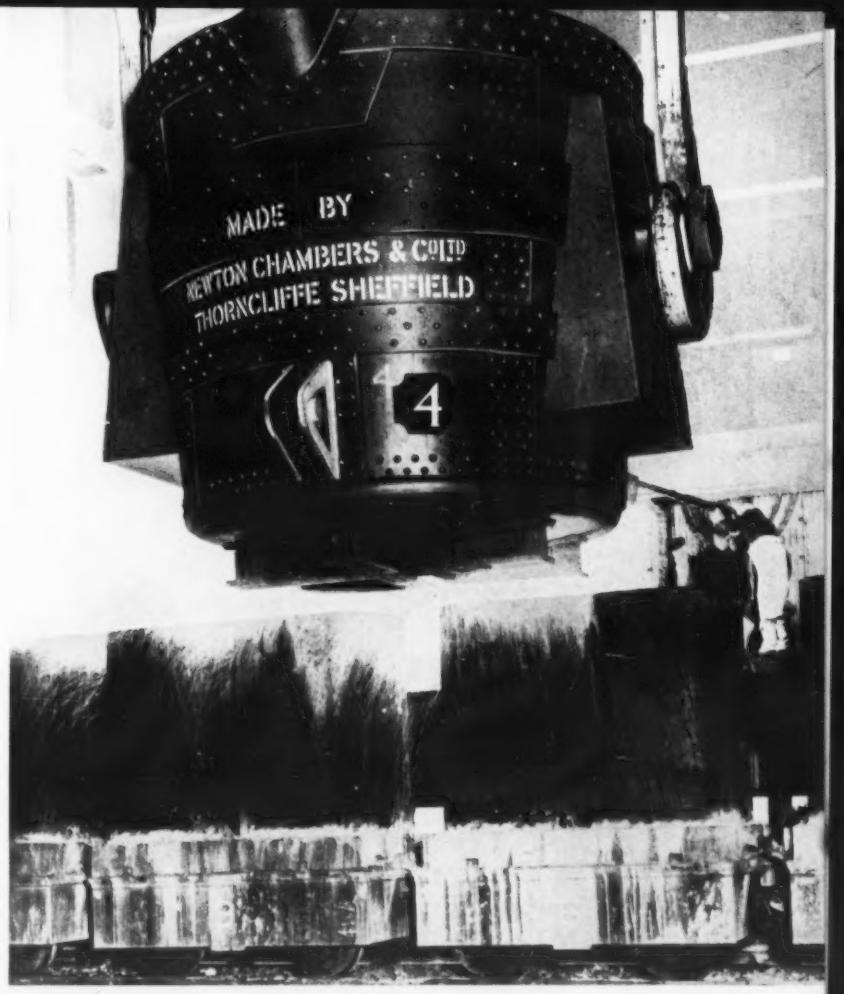
BELOW *275 ton ladles under construction at Thorncliffe.*



RIGHT *One of many steel casting ladles supplied to John Summers and Sons Limited.*



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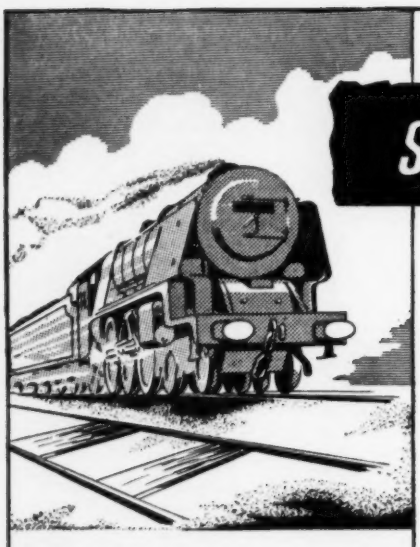

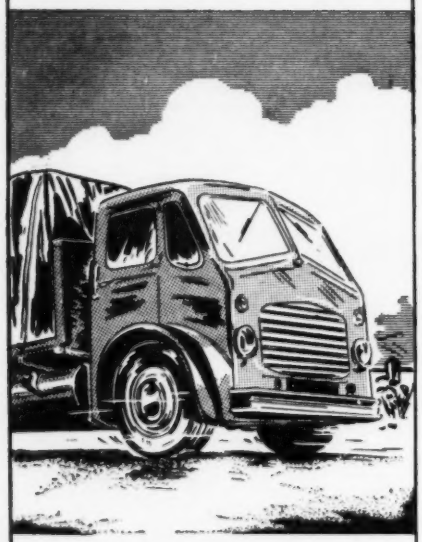

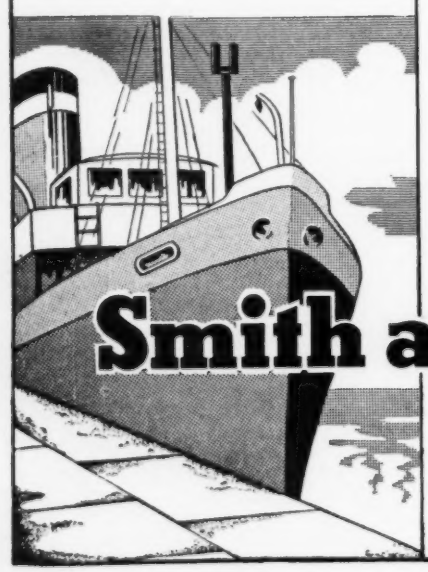

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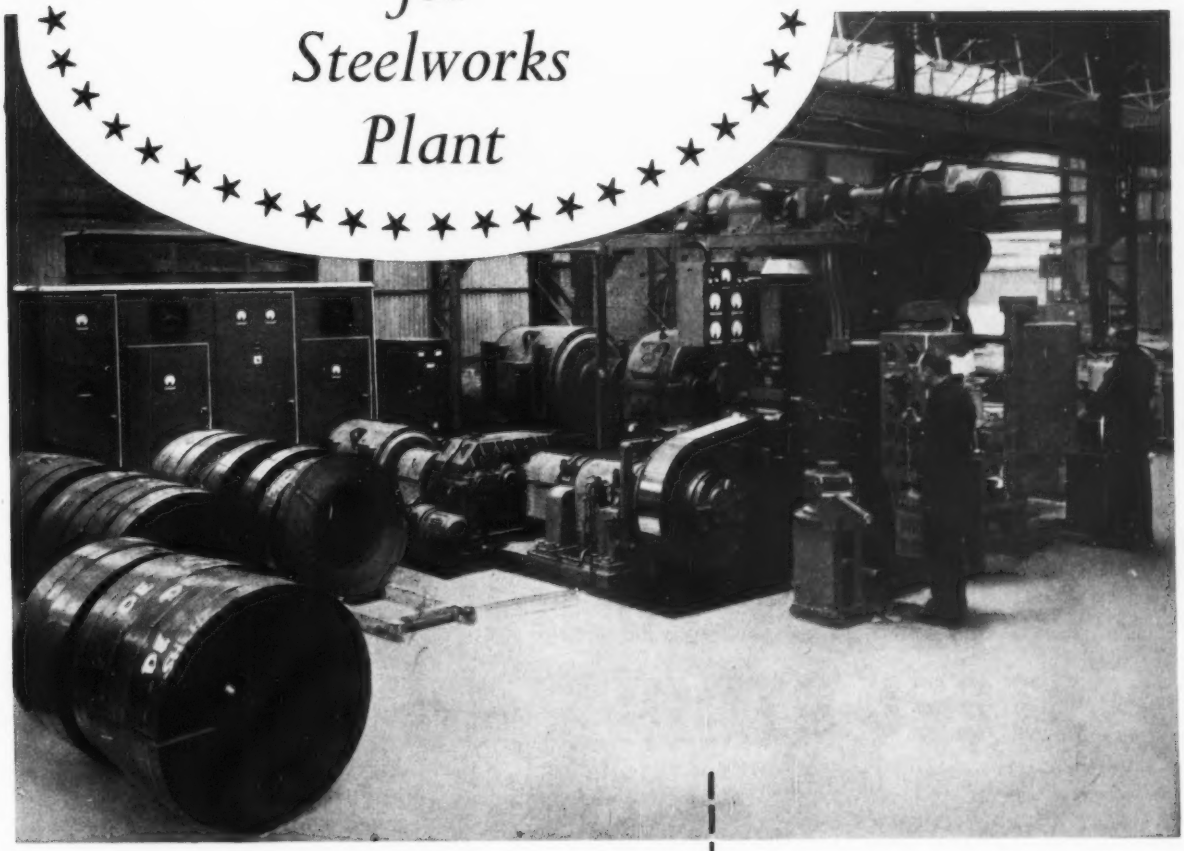

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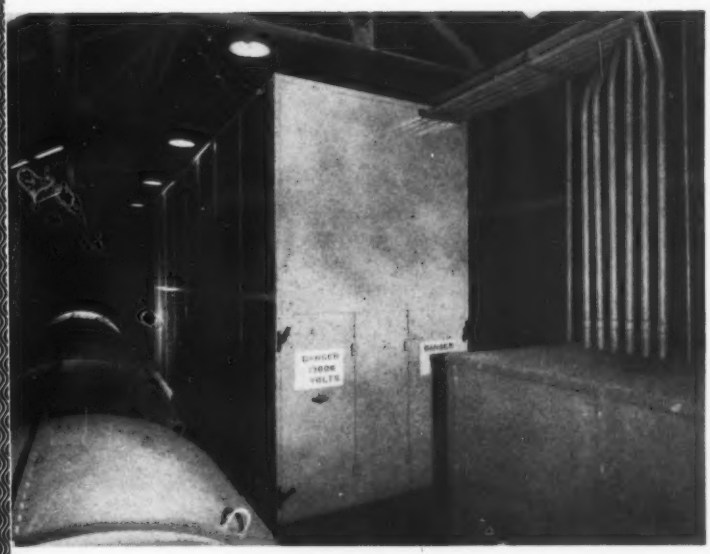
TRION

Electronic Air Filters for the Iron & Steel Industry



A Trion Electronic Air Filter installation cleaning the cooling air supplied to electrical equipment in a strip mill at the Hawarden Bridge Steelworks of Messrs. John Summers & Sons Ltd. The lower illustration shows the inlet face of the filter.

The extremely high efficiency of the Trion Electronic Air Filter, 90% Photometric Basis (99·5% on a weight basis), makes it eminently suitable for a wide variety of applications in the Iron and Steel Industry. It ensures that electric motors, switchgear and sensitive instruments are given adequate protection against the troublesome mass of small particles which can be the major cause of expensive breakdowns.

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Bustle main of Queen Victoria Blast Furnace showing 'gunned' lining in Tri-Mor Dense 'Guncrete'. (Inside diameter of shell 5 feet. Thickness of 'Guncrete' lining 9 inches).
Photograph by courtesy of the Appleby-Frodingham Steel Co. (Branch of the United Steel Companies Ltd.).

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TRI-MOR *Standard Castable*

A medium texture refractory having negligible shrinkage up to 1,350 C. Suitable for casting special shapes or for monolithic structures. Limiting service temperature 1,350 C.

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A similar refractory to Tri-Mor Standard Castable, but specially developed to have very high mechanical strength over the lower temperature range. Maximum service temperature 1,250 C.

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Suitable for face temperatures up to 1,600 C; has an extremely high resistance to thermal shock; used for cast in situ monolithic structures and for pre-cast refractory shapes; can be applied with a cement gun.

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Full details of each grade are available on request.

MORGAN Refractories Ltd

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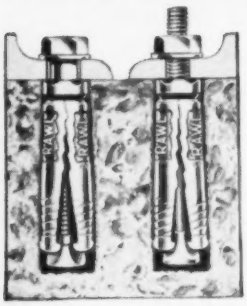
Rawlbolts have earned a sterling reputation for strength and reliability throughout the world—they are used by the million every month. Rawlbolts grip by *expansion*—their strength as a fixing is based on the enormous compressive strength of concrete itself.



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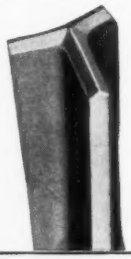
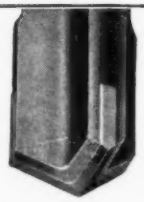
For use in hand and electric drills for Rawlbolt sizes C to G.

TRIFORM DRILLS

For use in electric hammers for Rawlbolts sizes C to K.





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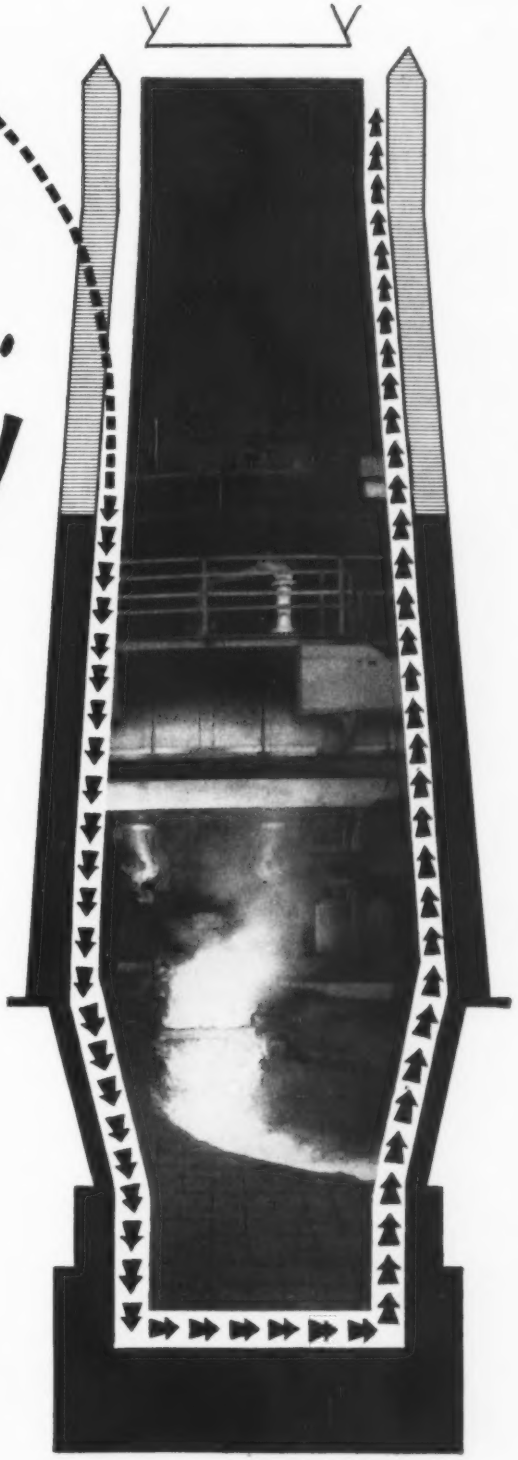

Photograph by courtesy of Appleby-Frodingham Steel Company (Branch of the United Steel Companies Limited)

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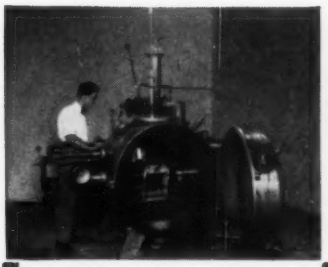
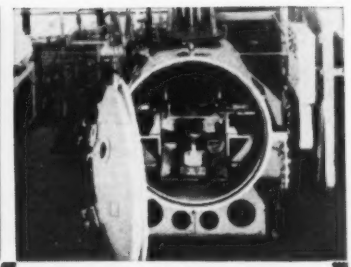


Model 2555 Vacuum Induction Furnace with melting capacity of 50 pounds of steel. Other standard furnaces have capacities of 12 to 3,000 pounds.



Model 2705 Non-Consumable Arc Skull Furnace with a capacity of 50 pounds of titanium. Other standard vacuum arc furnaces have capacities of 8 to 10,000 pounds of titanium.

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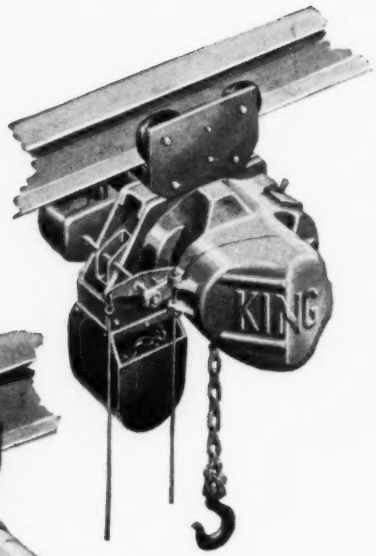

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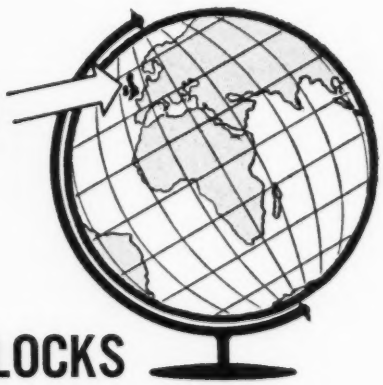

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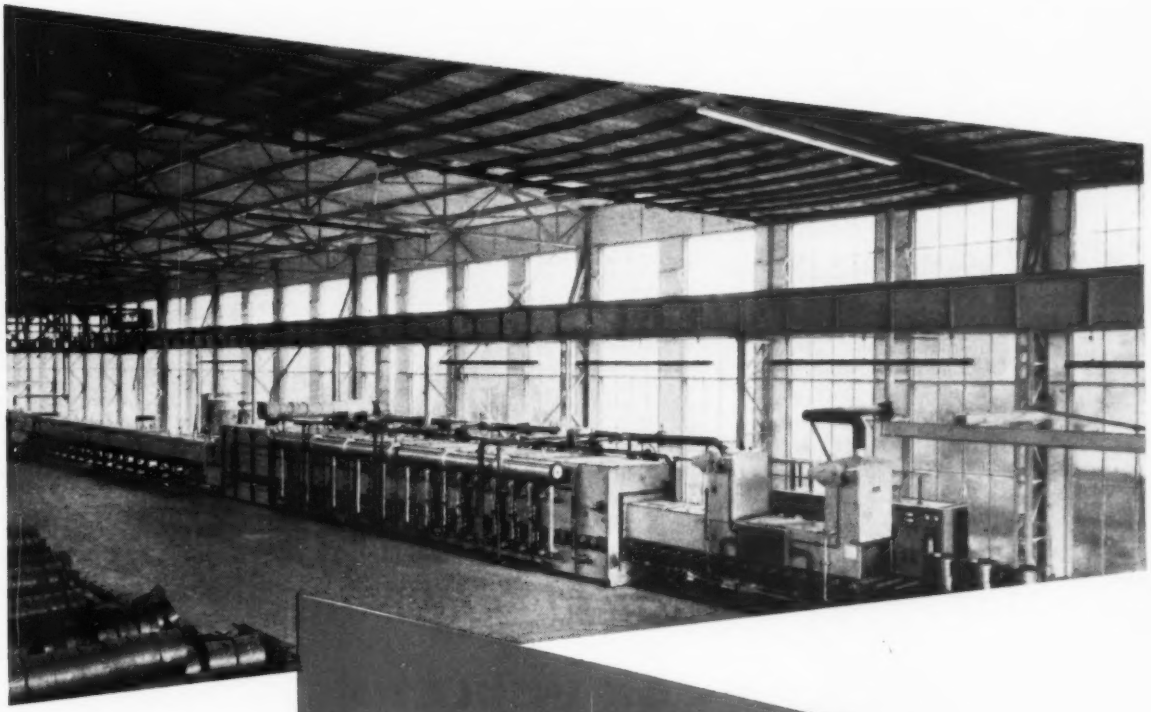

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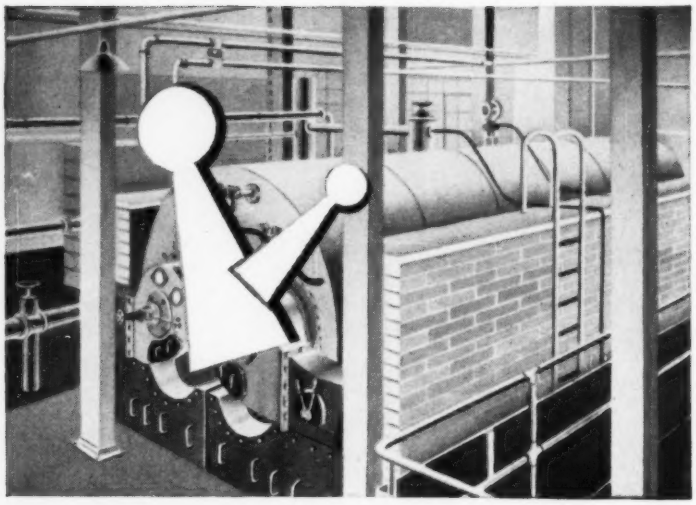

Inside information

ON INSULATING BRICKS

Insulating bricks hold heat in place, make use of every available degree and save vital, expensive fuel. Boilers insulated with these bricks maintain an even temperature which reduces wastage of materials.

Those are the bare facts on **all** insulating bricks. Further than that we cannot make claims for insulating bricks in general. But we **can** particularise on Newalls Nonpareil and Newparex insulating bricks and say much more.

We know these bricks, because of their combined strength and thermal efficiency, can be used time after time and retain complete efficiency up to temperatures of 2012°F.

We know that they are completely uniform in quality and size, are manufactured from special materials and are of scientifically determined structure and are an investment to any firm interested in efficient thermal insulation.

Newalls
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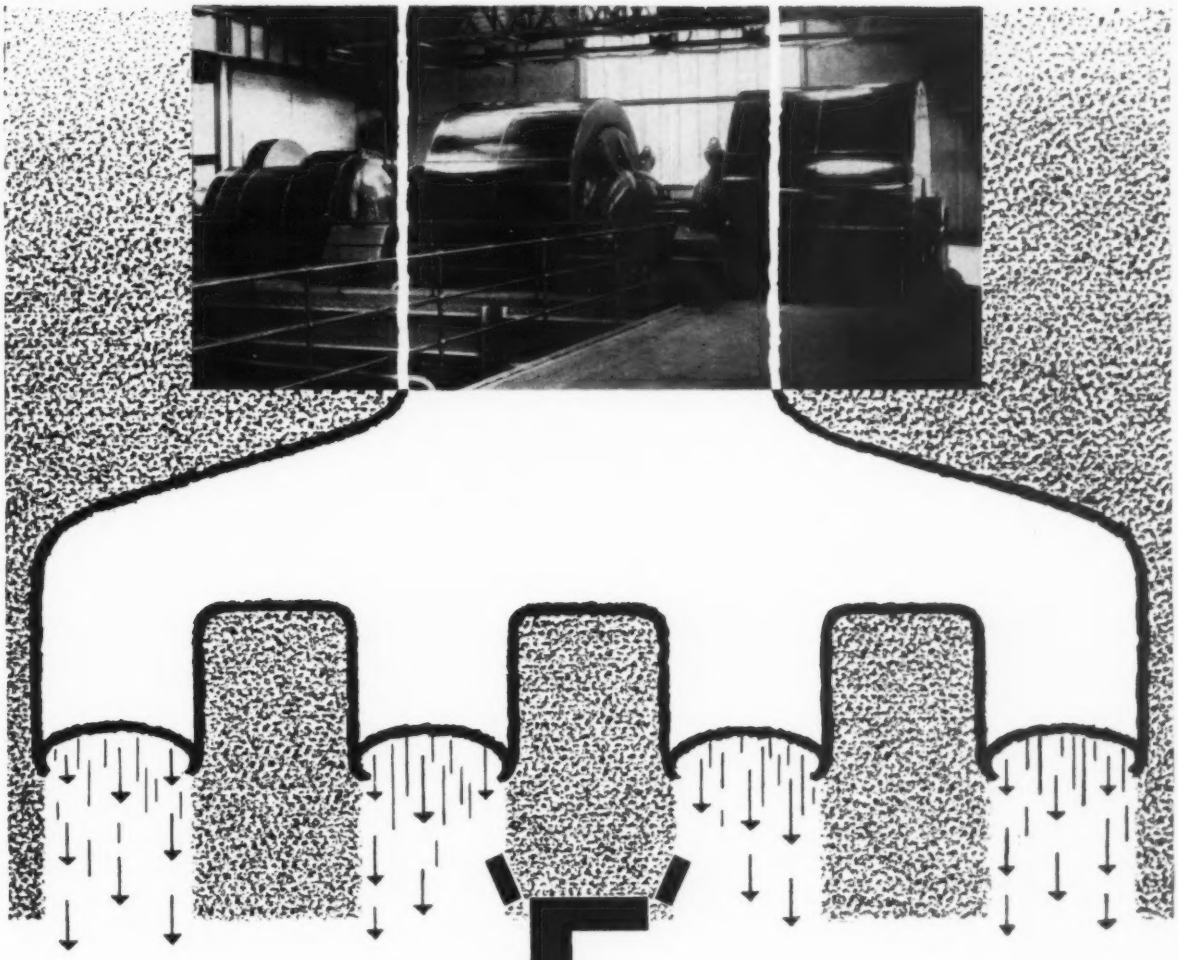

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The world's largest turbo-blower was built and installed by Parsons at the Scunthorpe Works of the Appleby Frodingham Steel Company Branch of the United Steel Companies Limited.

Known as the 'E' Blower, it is designed to supplement the output of the four smaller turbo-blowers, also built and installed by Parsons, or to act as a separate unit blowing air direct to any one, or two, of the four blast furnaces at this modern iron works.

PARSONS

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'E' Blower is capable of delivering 160,000 cubic feet of free air per minute at a pressure of 35 lb. p.s.i.

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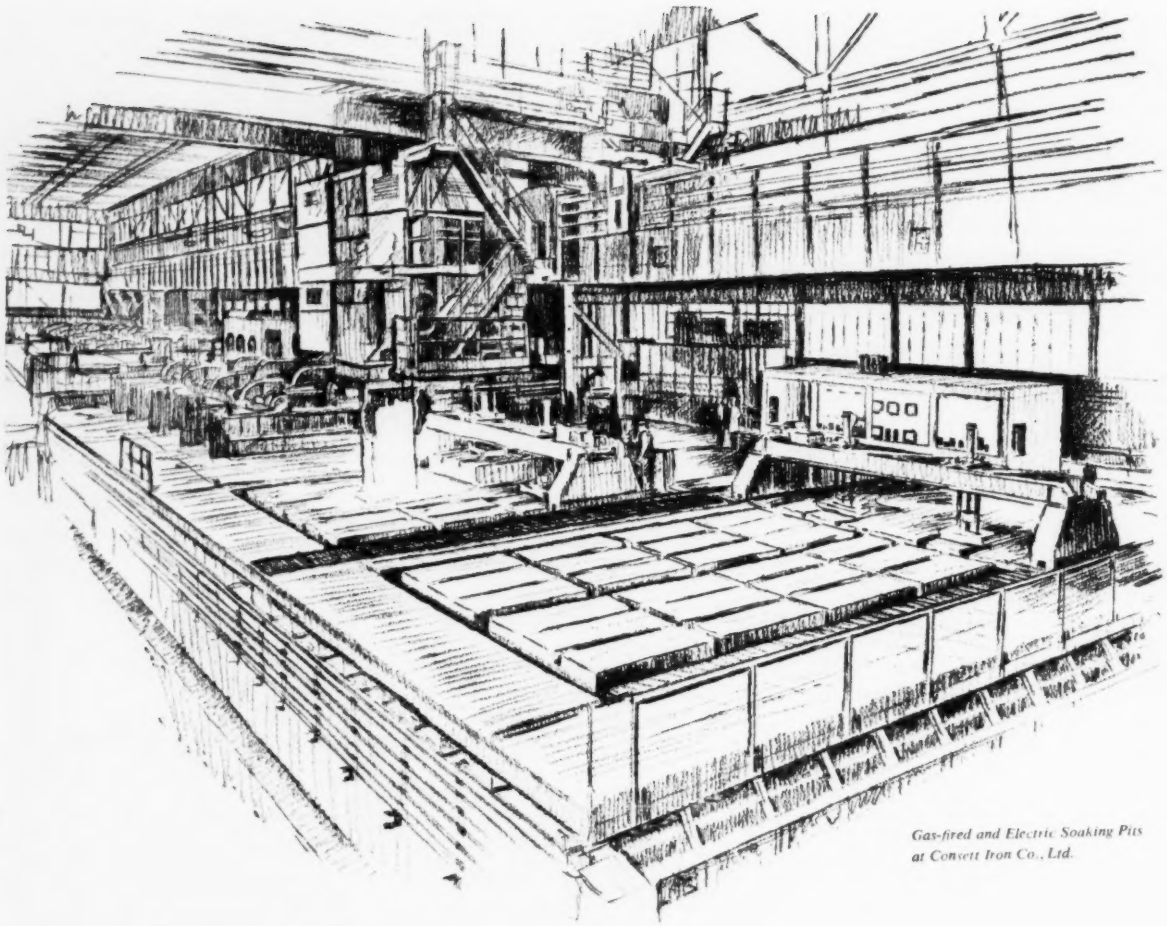

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Electric Soaking Pits for short track time tonnage steel.

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For the most economic method of dealing with a wide range of ingot track times, instal a combination of electric and fuel fired pits

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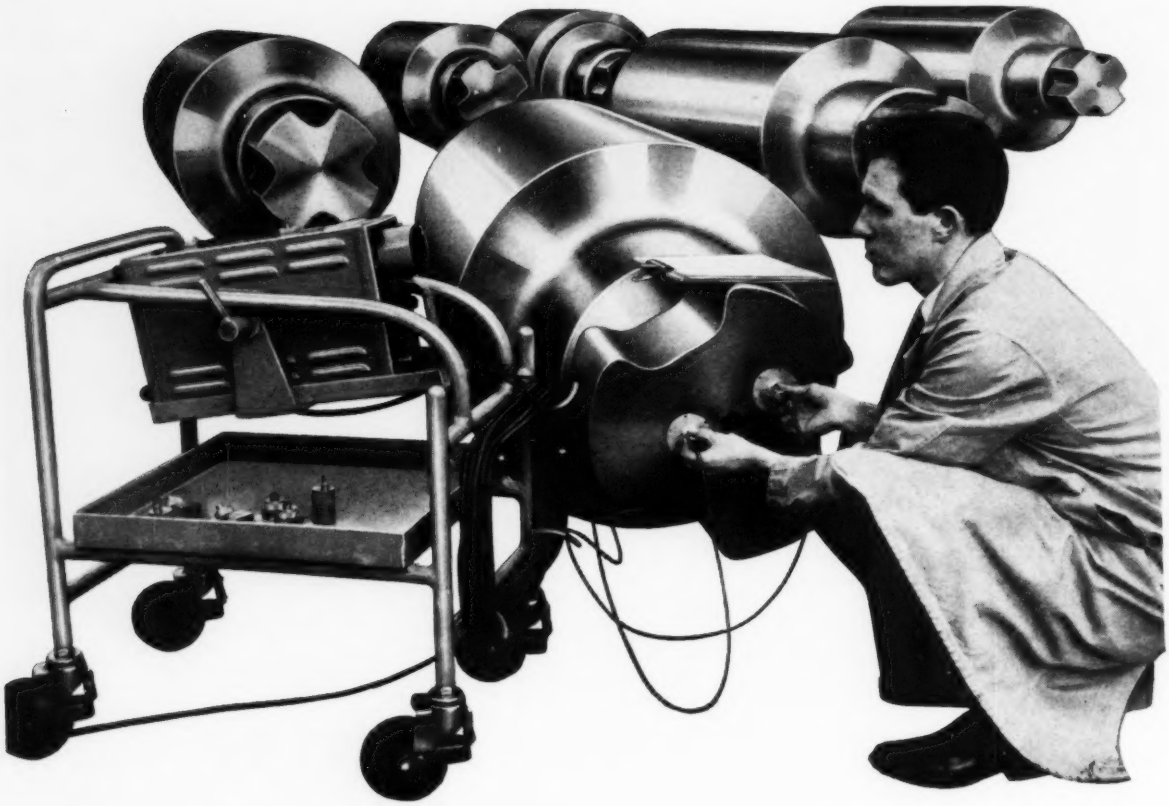

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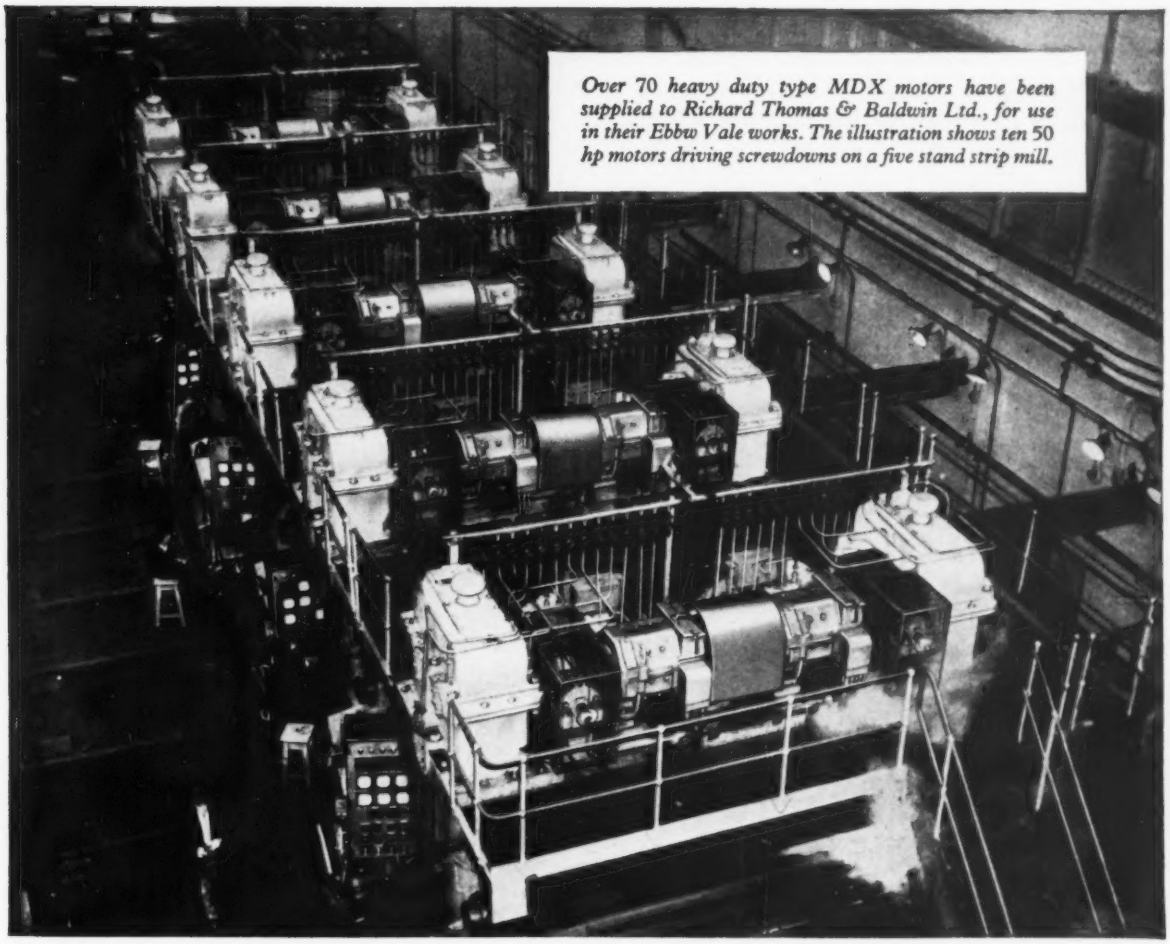

Over 70 heavy duty type MDX motors have been supplied to Richard Thomas & Baldwin Ltd., for use in their Ebbw Vale works. The illustration shows ten 50 hp motors driving screwdowns on a five stand strip mill.

All motors here are type MDX

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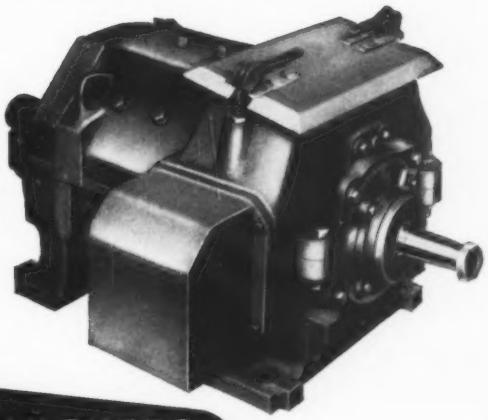

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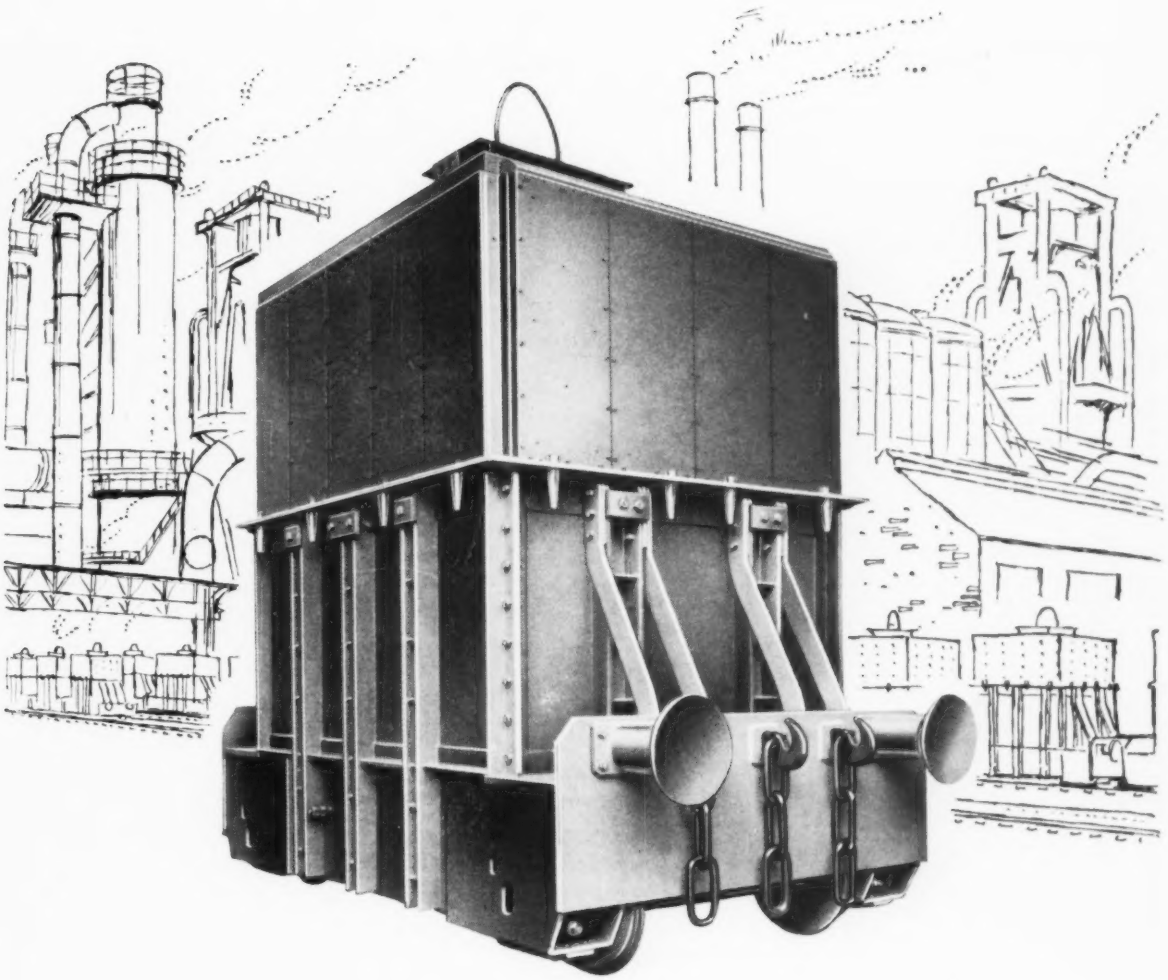

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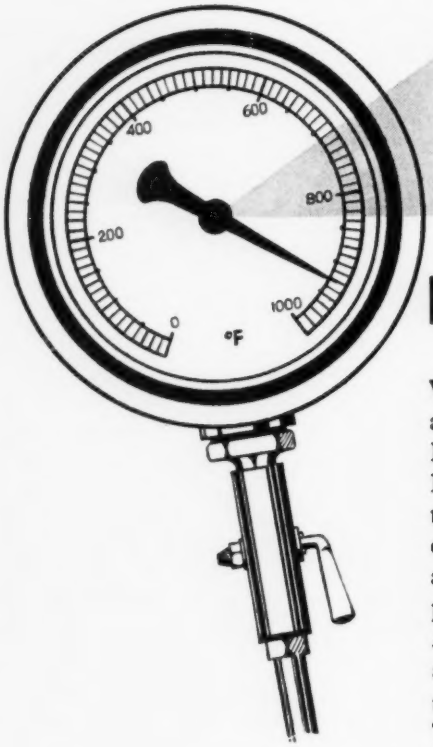

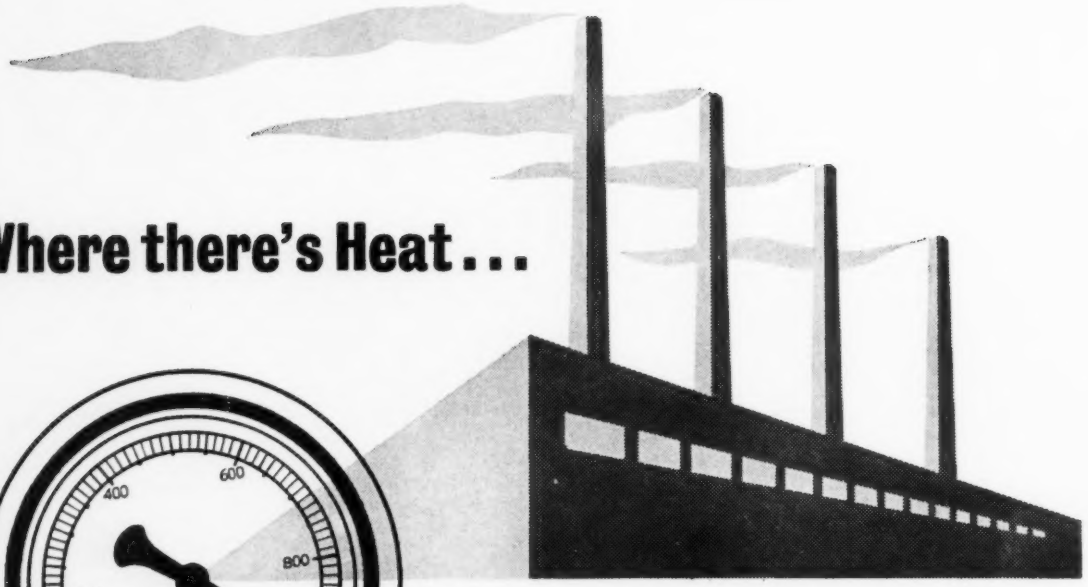

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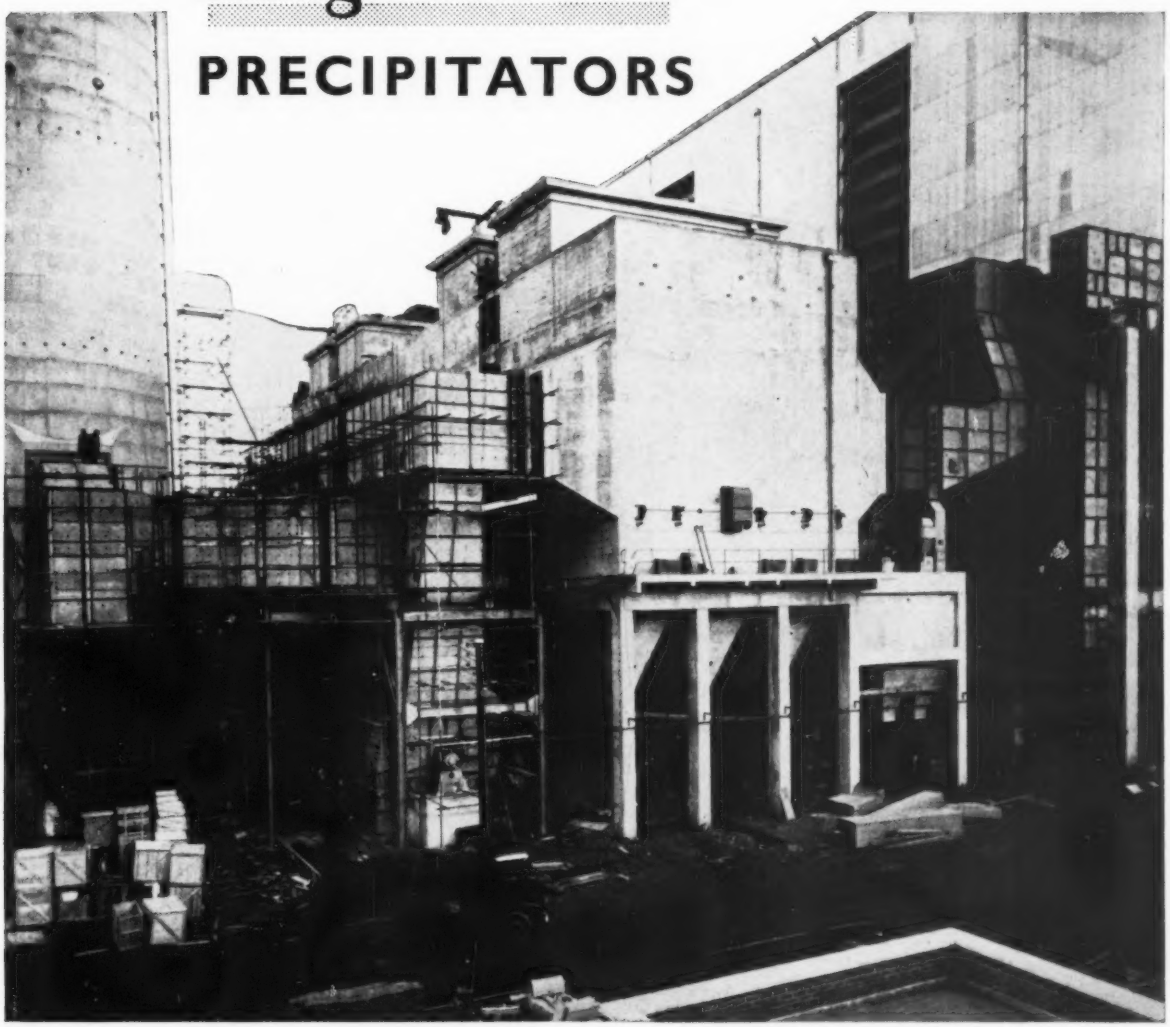

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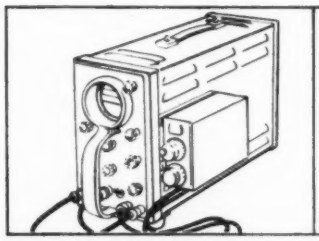
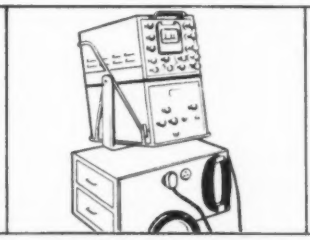
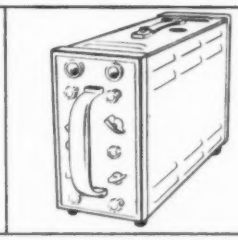


Flaw Detectors Marks 5F, 5AF. *Portable instruments with similar basic specifications. The 5F is a multi-frequency instrument for use with twin or separate type probes, whilst the 5AF, a single frequency instrument, either 1½, 2½ or 5 Mc/s. Also operates with single type probes. (Shown with Depth Gauge attachment).*



Flaw Detector Mark 6. *Trolley mounted transportable equipment, very powerful and versatile for use with all types of probes and having an exceptionally wide frequency range and high sensitivity.*



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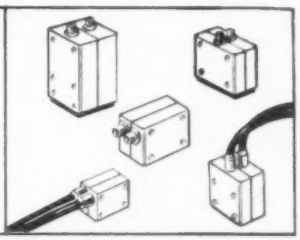

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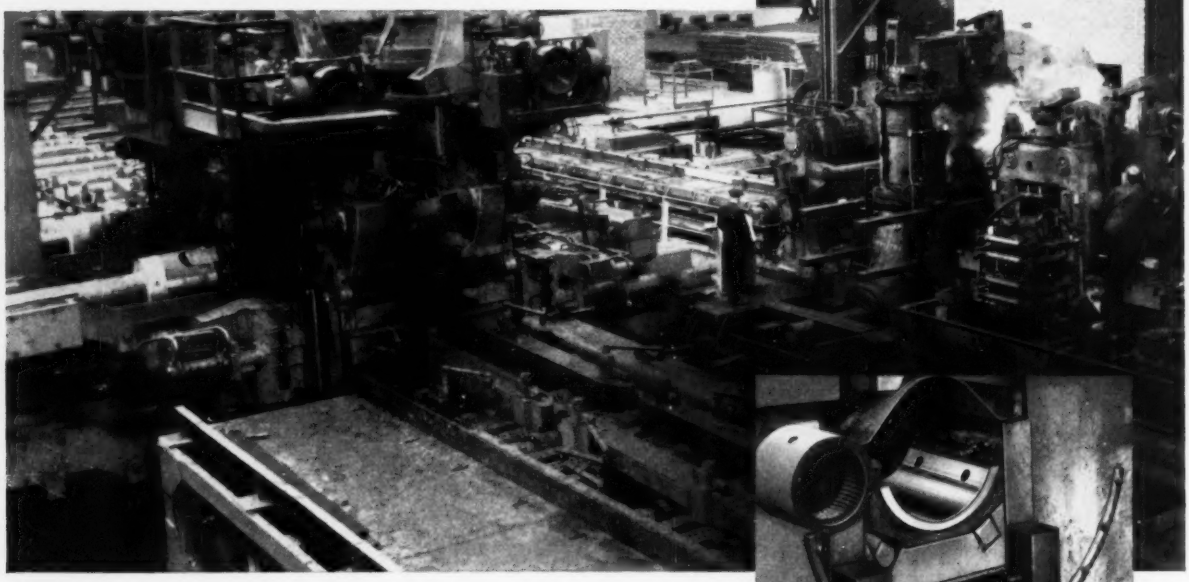

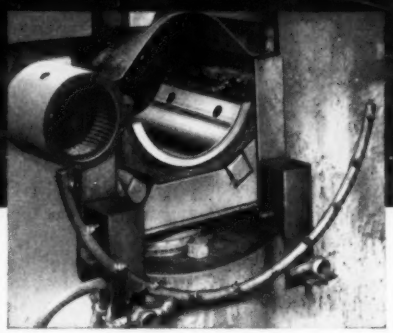

Roll stand during Roll changing period. Lower Railko bearing in position with water spray.

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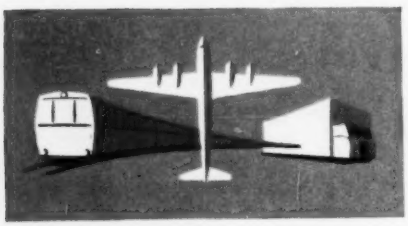

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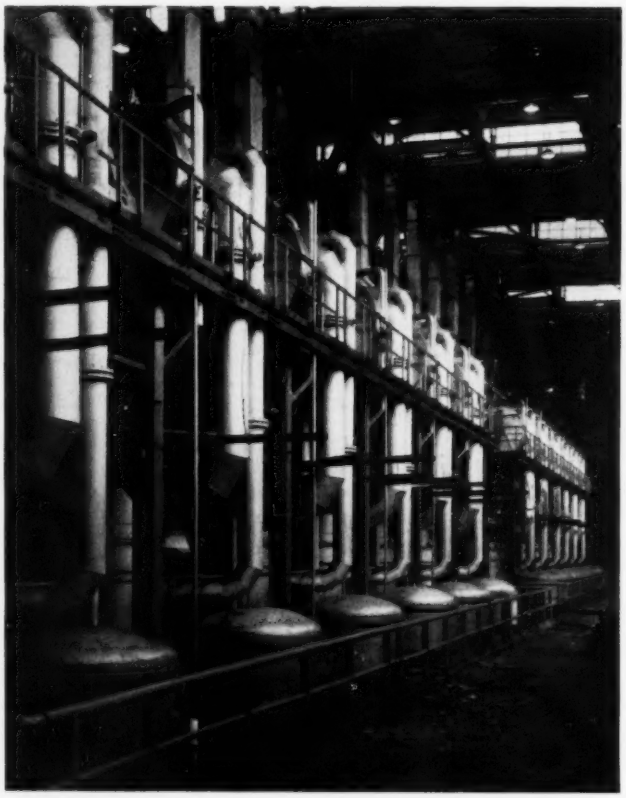

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Journal of The Iron and Steel Institute

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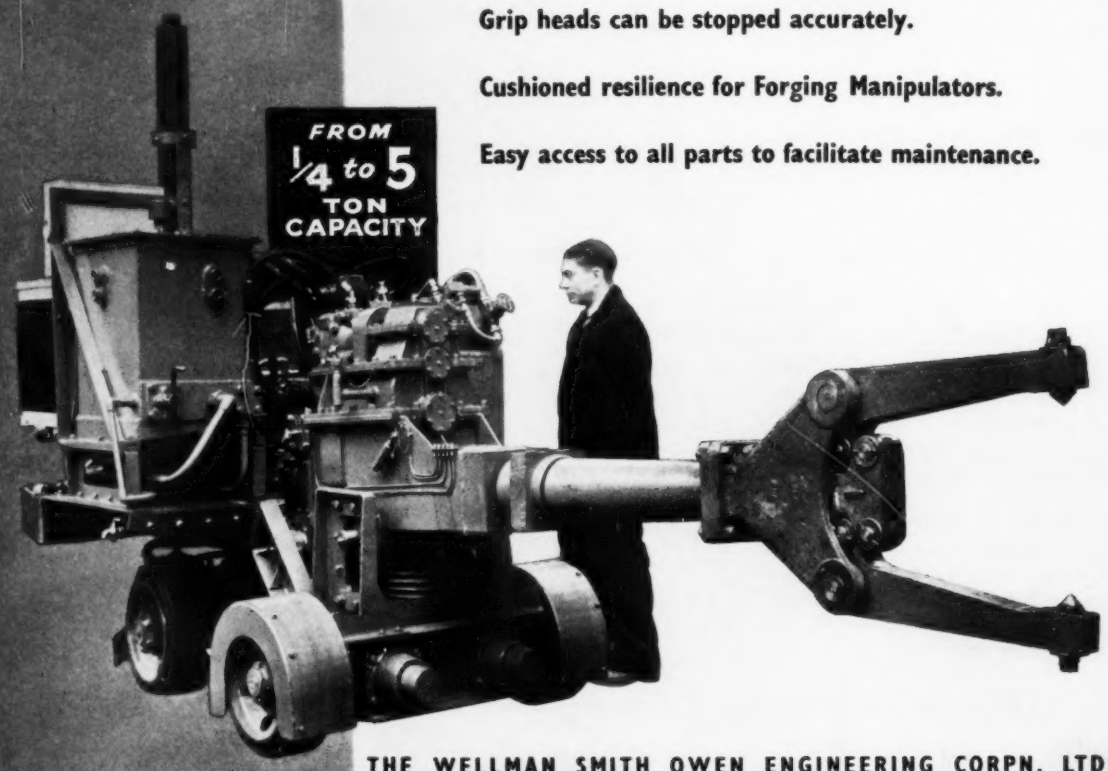

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J. H. CHESTERS, D.Sc. (Tech.), Ph.D.

JOHN HUGH CHESTERS first became interested in steelmaking when he was awarded a Metropolitan Vickers Scholarship in 1928 to study the problem of refractory materials for the induction furnace. He had just graduated with honours in physics at the University of Sheffield, to which he came from King Edward VII School, Sheffield, and carried out his early researches with the late Dr W. J. Rees. Following the award in 1931 of the degree of doctor of philosophy for his work on induction furnaces, he won a Robert Blair Fellowship, which took him to the Kaiser-Wilhelm-Institut für Silikatforschung in Berlin, where he worked for a year on the hydration of magnesia. After a year in Germany and interim visits to Austria and Czechoslovakia, he was awarded a Commonwealth Fund Fellowship, which he held at the Department of Ceramic Engineering of the University of Illinois from 1932 to 1934. Here he carried his researches on magnesia into the high-temperature field, and developed the reaction–expansion method of studying high-temperature reactions, e.g. the silica conversions and the formation of spinels. At the invitation of the late Dr T. Swinden he returned to the UK in 1934 to take charge of the refractories section of the newly formed Central Research Department of The United Steel Companies Ltd.

In 1945 he was awarded the degree of doctor of technical science at the University of Sheffield for his research on refractories, and in particular, his book on "Steelplant Refractories", first published in 1944. At about the same time he was made Assistant Director of Research, under Mr F. H. Saniter, of the expanded Research and Development Department of United Steel. In this new capacity he has been particularly interested in the aerodynamics of furnace design and heat transfer in open-hearth furnaces. The results of co-operative work with the British Coal Utilisation Research Association, the British Iron and Steel Research Association, and the University of Sheffield, in this field, have been summarised in ISI Special Reports nos. 37 and 59. In recognition of his research on refractories, and his contribution to Special Report no. 37, he was awarded the first Sir Robert Hadfield Medal in 1946, while in 1951 he was awarded the Robert W. Hunt Award of the American Institute of Metallurgical Engineers, for his paper on "Flow patterns in open-hearth furnaces".

Dr Chesters joined the Institute in 1939, and was made a member of Council in 1958. He has for some time been a member of the Publications Committee and was recently made Chairman of the newly formed Meetings Sub-committee. He is also Chairman of the Steel Practice Committee of the British Iron and Steel Research Association and the joint All-Basic Furnace Sub-committee of the British Iron and Steel Research Association and the British Ceramic Research Association. He is a Fellow of the Institute of Fuel, the American Ceramic Society, and the Institute of Ceramics. He is also a past-president of the British Ceramic Society.

J. H. Chesters, D.Sc.(Tech.), Ph.D.
Member of Council

PROCEEDINGS OF

THE INSTITUTE

Reports of Council · Meetings · Notices

Autumn General Meeting, 1958

The AUTUMN GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday, 10th December, 1958, at the Great Hall, Caxton Hall, Caxton Street, London, S.W.1, with the President, Mr C. R. WHEELER, C.B.E., in the Chair.

Minutes of the previous meeting

The minutes of the Annual General Meeting held in London on 7th and 8th May, 1958, were taken as read and confirmed.

Welcome to members and visitors

The **President** welcomed those present and, in particular, the large number of members from overseas; representatives were present from Austria, Belgium, France, Germany, Holland, Luxembourg, Norway, Spain, Sweden, Switzerland, the USA, and the USSR.

Obituary

The **President** referred to the loss which the Institute had suffered by the death of 26 Members. He referred in particular to the loss of four Members of Council and two Honorary Members. Dr C. H. Desch, F.R.S., who died on 19th June, had joined the Institute in 1913, became a Member of Council in 1924 and a Vice-President in 1930, and had served as President from 1946 to 1948. Mr S. Thomson, who died on 7th September, joined the Institute in 1937, became a Member of Council in 1951, and was appointed a Vice-President in 1958. Professor C. A. F. Benedicks, who died on 16th July, joined the Institute in 1905 and became an Honorary Vice-President in 1922. Mr E. D. Bool, who died on 1st December, joined the Institute in 1935 and became an Honorary Member of Council in 1958. Mr W. H. Eisenman, who died on 30th May, became an Honorary Member in 1955. Monsieur J. Raty, who died on 20th June, became an Honorary Member in 1956.

Election of Honorary Member

The **President** went on to present the diploma of an Honorary Member of the Institute to Dr Harold Moore, C.B.E., who had been a member of the Institute for over 50 years. Before making the presentation, he summarized Dr Moore's distinguished career.

Dr **Harold Moore**, C.B.E., in reply, said that a scientific weekly recently published a profile of one of his contemporaries with the reference "This is the age of the octogenarian." He had regarded that as a piece of pleasant journalistic fantasy until he was awarded the Honorary Membership of The Iron and Steel Institute, which had made him think that perhaps there was something in it.

He appreciated the award enormously, and thanked the President very much for his very kind words.

Announcements

Changes on Council

The **Secretary** (Mr K. Headlam-Morley) reported the following changes on the Council since the last General Meeting in May, 1958:

Vice-President:
Mr D. A. Oliver, C.B.E.

Member of Council:
Mr R. F. Summers

Hon. Members of Council:

Mr T. H. Stayman, President of the Cleveland Institution of Engineers, in place of Mr T. W. Thursfield.

Mr P. T. Edwards, President of the Ebbw Vale Metallurgical Society, in place of Mr J. T. Mills.

Mr K. Hill, President of the Leeds Metallurgical Society, in place of Mr P. A. Green.

Mr Johnson Y. Davies, President of the Manchester Metallurgical Society, in place of Dr K. M. Entwistle.

Mr H. H. Stanley, Chairman of the Newport and District Metallurgical Society, in place of Mr C. I. F. Mackay.

Mr W. H. B. Wesson, President of the Staffordshire Iron and Steel Institute, in place of Mr G. Parkin.

Additional Hon. Members of Council, elected following announcement at last General Meeting in May, 1958:

Mr R. W. Evans (Steel Company of Wales Ltd.)

Dr L. Northcott (Armament Research and Development Establishment).

The following were due to retire at the next Annual General Meeting and were eligible for re-election:

Vice-Presidents: Mr E. T. Judge, Mr F. H. Saniter, and Dr C. Sykes, F.R.S.

Members of Council: Mr C. H. T. Williams, Professor A. G. Quarrell, Mr B. C. Talbot, Mr E. W. Colbeck, and Lt. Com. G. W. Wells.

Andrew Carnegie Scholarships

The following awards had been made since the last General Meeting:

£400 to R. E. M. Ball (Imperial College, London): (2nd grant): To assist research on "The effect of length of test-piece and stored energy on the brittle fracture of steel."

£400 to W. D. Brentnall (Manchester University): To assist research on "The structure of metallic meteorites."

£380 to I. M. Davidson (Liverpool University): (2nd grant): To assist research on "Oxygen potentials in simple slags."

£400 to K. Farrell (Sheffield University): To assist research on "The embrittling effect of hydrogen on ultra-high-tensile steels."

£80 to A. Gilbert (Liverpool University): (2nd grant): To assist research on "The effect of alloying elements on martensite strata temperatures."

£380 to J. G. Humphreys (Liverpool University): (2nd grant): To assist research on "Carbide constituents in iron–carbon–silicon alloys."

£250 to E. F. Ibrahim (Sheffield University): To assist research on "An investigation of martensite transformation curves."

£80 to C. N. Reid (Liverpool University): To assist research on "Experimental study of time-dependent strain in iron at sub-zero temperatures."

Dates of Meetings in 1959

i. *Annual General Meeting* in London on Wednesday and Thursday, 6th and 7th May, 1959. Dinner for Members on Wednesday, 6th May, 1959.

ii. *Special Meeting* on the North-East Coast, 6th to 10th July, 1959.

President-Elect

The **President** proposed, on behalf of the Council, that Mr W. Barr, O.B.E., Honorary Treasurer, be nominated for election as President, to take office at the Annual General Meeting in 1959, and to serve for one year. Mr Barr joined the Institute in 1925, became a Member of Council in 1948, and Honorary Treasurer in 1953.

Honorary Treasurer

The **President** said that the Council had invited Mr E. (now Sir) Julian Pode to follow Mr Barr as Honorary Treasurer. His appointment would take effect from a convenient date, probably in March.

Election of Members

Mr **D. J. D. Unwin** and Mr **J. H. Flux,** the scrutineers of the ballot, reported the following elections:

MEMBERS

Allen, James (Worcester); **Alwan,** Abdul Sahib, B.SC., F.G.S. (London); **Atkins,** William Sydney Albert, B.SC.(HONS.ENG.), M.INST.G.E., M.I.STRUCT.E., M.I.W., M.CONS.E. (London); **Avis,** Roy William Henry, A.M.I.MECH.E., A.M.I.STRUCT.E. (Peterborough); **Bargone,** Agostino, PROF.DR.ING. (Padua, Italy); **Beale,** Colin Ogden, A.I.M. (Thornaby-on-Tees); **Bessemer,** Alan Frederick (Worcester, Mass., U.S.A.); **Bishop,** Raymond John, B.SC.ENG.(MET.), A.I.M. (Wolverhampton); **Boelens,** Edgard Jean Edouard (Grivegnée, Belgium); **Boniszewski,** Tadeusz, DIPL.ING. (Krakow, Poland); **Brandl,** Adolph, DR.ING. (Duisburg, Germany); **Bromley,** Charles Herbert (Leicester); **Brown,** Leslie Samuel (London); **Calbiani,** Guido (Milan, Italy); **Cavanagh,** Raymond Leigh, B.A.SC.(MET.) (Toronto, Ont., Canada); **Chandler,** Kenneth, B.SC., A.R.S.M. (London); **Cherry,** Arthur William, A.M.INST.C.E. (London); **Clay,** Stanley (Turnbridge, Huddersfield); **Coles,** Douglas Harry, B.SC., A.M.I.MECH.E., A.M.I.E.E. (London); **Coppée,** Evence (Brussels, Belgium); **Courtney-Sutton,** Roland (Wolverhampton); **Crane,** F. A. A., B.SC.ENG.(MET.)HONS., A.R.S.M., A.I.M. (Ipswich); **Cudby,** Joseph William, A.MET., L.I.M. (Workington); **Dash,** David Bryan (Cardiff); **Delaunay,** Georges (Paris, France); **De Posson,** Alexandre (Liège, Belgium); **Di Candia,** Armando, D.CHEM. (Genoa, Italy); **Dorville,** Robert (Metz, France); **Dumitrasco,** Pierre (Bucharest, Roumania); **Edwards,** John Owen, B.SC., A.I.M.M., A.I.M. (London); **Einerkjaer,** John (Oslo, Norway); **Elkan,** Robert Max Ludwig, B.SC.(ENG.), A.M.I.MECH.E. (Bournemouth); **Evans,** Owen Thomas, ASSOC.M.C.T., A.M.I.E.E., A.M.I.MECH.E. (Manchester); **Faivre,** René, DR.-ÈS-SC. (Nancy, France); **Fender,** Harold William (Wednesbury); **Fielden,** Cyril Frederick Raymond, ASSOC.I.E.E. 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(Birmingham); **Ward,** Roger Neville Macleod (Cardiff); **Waring,** Peter, L.I.M. (Hemel Hempstead); **Wasmuht,** Roland, DR.ING. (Essen, Germany); **Watson,** John Gerald, B.A. (Middlesbrough); **Wauthier,** Louis (Flémalle-Haute, Belgium); **Weston,** William Charles (Wednesbury); **Wickwire,** Ward W., Jr., B.A. (Pittsburgh, Pa., USA); **Wieland,** George, A.M.I.MECH.E. (Brierley Hill); **Wilson,** Robert (Dundee); **Wood,** Anthony Arthur Robinson, A.R.I.C. (Chessington); **Woods,** John Victor, B.SC., A.M.I.E.E. (Norwich); **Wright,** John Davidson, A.MET., A.I.M. (Sheffield); **Wscieklica,** Janusz, M.S.(MET.ENG.) (Minas Gerais, Brazil).

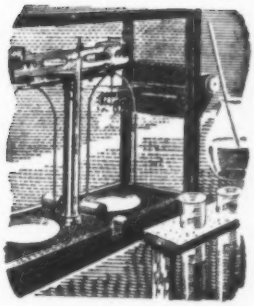
ASSOCIATES

Bennett, Gordon Henry John, B.SC. (Sheffield); **Beswick,** Derek Watts (Stoke-on-Trent); **Carruthers,** Robert Brian (Durham); **Clarke,** Herbert, B.SC. (Nantyglo, Monmouthshire); **Gloyn-Cox,** Laurence David (London); **Hanson,** Owen Jerrold, B.A. (London); **Hobson,** Alan (Middlesbrough); **Kibble,** Frederick (Bilston); **Kothari,** Navin Chandra M., B.SC. (Raleigh, N.C., USA); **Martin,** Norman (Cambridge); **Muller,** Tobias Lefebre Francois, B.SC. (Vereeniging, South Africa); **Northcott,** W. J., B.A. (Sheffield); **Ozturk,** Yildirim, B.SC. (Sheffield); **Pickering,** Arthur George (Bilston); **Proebstle,** Richard Alan, M.S.MET.ENG. (Troy, N.Y., USA); **Riviere Cera,** Juan José, B.SC. (Barcelona, Spain); **Sanderson,** George Patrick, ASSOC.MET., L.I.M. (Sheffield); **Smales,** Richard (Swansea); **Wilkins,** Brian John Samuel, B.SC.(ENG.)MET. (London); **Wright,** George Hodgson (Leicester); **Wright,** Kenneth John (Bilston).

The **President** declared those candidates to be duly elected. They numbered 171, and the total membership of the Institute was now 5 107.

PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research



Defects in steel: a tentative theory

By T. F. Pearson, M.Sc.

SYNOPSIS

A statistical survey of the defects occurring in a total of over 1000 casts of basic semi-killed plate steels has been made during three periods over several years.

It has been found that if the casts are classified according to the silica contents of their tapping slags, then the average defect values expressed quantitatively when plotted against the silica contents, give rise to a characteristic and complex curve which shows a minimum average defect level at 13–14% silica.

Graphs for each of the periods examined present the same fundamental shape, the minimum defects level always occurring at the same silica value.

It is concluded that all classified defects, particularly those involving the surface of the steel, have a fundamental common cause. A tentative theory based upon the influence of the silica in the slag on the silicon content of the metal (hitherto neglected in basic steel) is proposed.

It is suggested that the optimum silica content of the slag associated with the minimum defect level, is indicative of a ' balance ' between hydrogen and oxygen in the liquid metal, very similar to that pertaining in liquid copper in the ' tough pitch ' condition. Over a considerable range of slag compositions, normal additions made to the ladle to produce a desired chemical specification exert little influence on the condition of the metal leaving the furnace.

Mention is made of the possible significance of the theory with respect to rimming steels, and very recent work on this type has revealed that the carbon and manganese losses occurring during active rimming in the mould bear a relationship to the total iron contents of the tapping slags, which strikingly resembles in its form that of the defects curve for semi-killed steels. Hydrogen is suggested as a causative factor.

In conclusion the influence of different modes of refining on ' bath condition ' are considered and emphasis is laid on the importance of the slag as the governing factor in the production of quality steel.

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INTRODUCTION

A COMPREHENSIVE DEFINITION of the quality of a cast of steel must, apart from the user's viewpoint, contain some reference to its behaviour during actual processing. Obviously it is desirable to secure maximum yield through the absence of defects. Also, while different types of steel such as fully or semi-killed and rimmed, display differing yields arising from ingot structure, these yields for any type are capable of deviation below an average standard by reason of different cast characteristics. Such varying yields arise from two major causes:

(i) Internal features such as varying depths to which objectionable segregation may run in ingots of the same specification from different casts as revealed by standard cropping

(ii) External surface features which either persist or develop during heating and rolling. Examples are described by such terms as shell, pits, seams, spills, slivers, etc., and the existence of these may give rise to rejection or excessive dressing.

Manuscript received on 19th December, 1957.

The author is research manager at the Consett Iron Co. Ltd.

These metallurgical defects (as distinct from those which may be produced mechanically during rolling) have in the past received various explanations, one of the most familiar being to attribute ' shelly ' ingots to excessive splashing during teeming. Such an explanation dismisses the simple analogy of pouring any inert liquid such as mercury into a mould, in which case it is impossible to produce a bad surface. For some years the author has sought a more comprehensive and satisfactory explanation which could account for the many exceptions to the rule which are encountered in practice.

This paper attempts to develop a general theory to account for the occurrence of defects. It depends on the concept of a critical balance between hydrogen and oxygen in the liquid metal. This balance is achieved when the silica in the tapping slag has a certain value and it appears probable that this particular level of silica results in a certain value of silicon in the metal which (along with other residuals) in turn determines the activity of the oxygen present. The quantity of silicon is small and has hitherto been neglected in the basic bath.

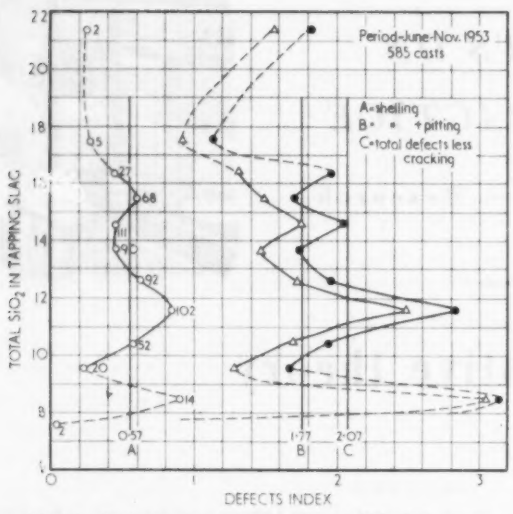


Fig. 1—Defects June–November, 1953, 585 casts

While mention is later made of the after-effects of hydrogen in the solid metal e.g. hair-line cracks (with which most of the available literature deals), the theory concerns primarily the coexistence of hydrogen and oxygen in the liquid metal and the possible behaviour of the two at the instant of change from liquid to solid state. Information on equilibrium conditions in liquid iron between carbon, hydrogen, and oxygen is extremely sparse.

DATA

A system of recording plate-mill defects was instituted some years ago, whereby faulty steel reaching the plate stage is expressed as a percentage of the ingot from which it came. Hence it is possible to account in turn for the total defective material from the whole cast and to express it by any suitable quantitative index. Variability between casts and their quality with respect either to individual defects or to all defects collectively, can then be expressed easily and possible relationships between these values and any production variable can be examined, assuming of course, that potential 'cause and effect' can indeed be related by common sense. Also, since little dressing at the slab stage was carried out during the collection of the results, a true quantitative assessment of the metallurgical defects relating to any cast became possible.

An examination of the intensity of the defects on this basis reveals a normal gaussian distribution, i.e. the majority of the casts is characterized by a certain level of defects, a smaller number of casts is excellent, while on the other side of the node increasingly bad casts show a diminishing frequency.

A feature of the recording system is that the defects are also classified according to type, e.g. pitting, shelling, cracking, lamination, etc., these being recorded by inspectors in the mill. There are certain weaknesses in the system. Some ingots may yield plate surfaces superior to others from the same cast, only because thinner plates have been rolled from them, i.e. more work has been applied. Results may be complicated also by the use of different moulds, again introducing differing degrees of work for the same plate thickness. A statistical examination may be vitiated however, if data are subdivided excessively so that average values in any one class have little or no meaning. To a considerable degree this difficulty can be overcome by random sampling, provided reasonable numbers are secured in any class. Adoption of this method has been compulsory in the present work. Tapping-slag analyses are not carried out for every charge owing to labour shortage. Slag samples from various furnaces are randomly chosen each week without reference to any other conditions whatever. Since billet steels are currently produced with plate steels on all furnaces, then plate-steel casts for which slag analyses become available represent random sampling with respect to the results which emerge.

Plate steels generally form a convenient class for examination since they cover a relatively small range of percentage composition: 0·12–0·25C, 0·55–0·70 Mn, 0·02–0·05Si. Also, this class of semi-killed (or balanced) steels forms the major portion of the steel output of the country. The variable of composition therefore, is eliminated when considered relative to the range of compositions made, namely 0·06–0·90% C, with much wider ranges of both manganese and silicon, covering killed and semi-killed varieties.

An examination of billet steels was indeed purposely avoided because there is considerable difficulty in assessing the 'quality' of these in any truly quantitative manner. An ideal method might be the determination of the number of man-hours per ton involved in dressing but since even severe dressing does not necessarily involve rejection it was decided that plate casts provide more positively classifiable evidence of quality to a 'go' or 'not go' standard. The choice of plate results cannot be objected to on the ground of defect type because, while end-effects might differ owing to rolling differences (e.g. the greater surface spread in a plate) the origin of surface defects generally in both products at the ingot stage must be the same.

From an examination of the records for several

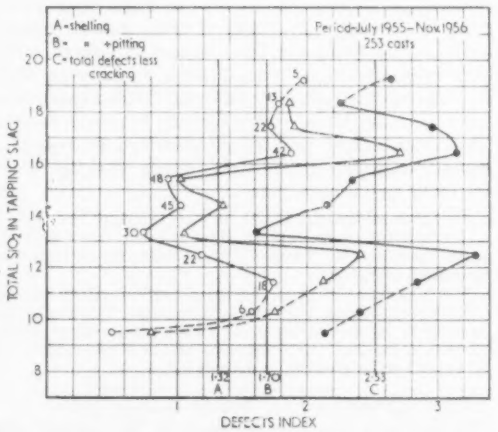


Fig. 2—Defects July 1955–November 1956, 253 casts

years, the period June–November 1953 was representative of normality in the weekly fluctuations of total plate-mill defect values. Both before and during this period no large changes towards increased production had been made and some 585 casts were examined for which tapping-slag analyses were available.

After this period production was increased by the introduction of the duplex process on certain furnaces and two further periods from July 1955 to November 1956 (253 casts) and from December 1957 to February 1958 (251 casts) were chosen for examination.

Examination of data

Many plots of the defects (mainly singly, e.g. pitting or shelling) for the first period were made against various slag constituents and such characteristics as basicity ratios or total acids. None of these revealed any suggestion of meaning except for the simple plot of silica against shelling. Here, an initial scattergraph appeared to suggest a trough in the defect index value over a certain limited range of silica. To clarify this, the slag silica contents were classified into a limited number of ranges between the extremes and average values for shelling were ascertained for each silica range. Curve *A* in Fig. 1 shows the result and it was the final achievement of this curve which prompted the examination of two later groups of casts in a similar manner to confirm (or otherwise) its character. These corresponding curves are marked *A* in Figs. 2 and 3.

The curves in Figs. 1–3 obviously form frequency curves of the occurrence of the various silica ranges in the slags and numbers available tend to diminish towards the outer limits of the silica values. Average shelling values for these extreme silica ranges are obviously much less reliable than those nearer the centre of the curve where greater numbers are involved. For this reason the ends of the curves are dotted and only the centre portion is regarded as significant. The significance of this type of curve is mentioned later in connection with other derived values and is examined more fully in a further section dealing with carbon and manganese losses from rimming steels.

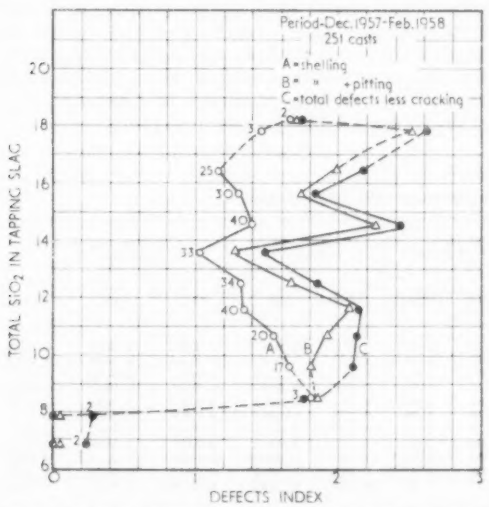


Fig. 3—Defects December 1957–February 1958, 251 casts

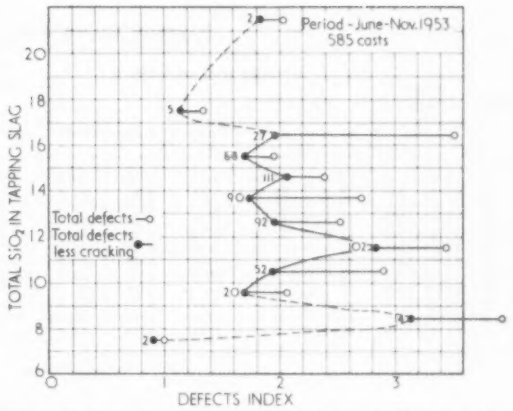


Fig. 4—Defects June–November 1953, including cracking

Inspection of all the curves marked *A* reveals a distinct minimum defect level at 13–14%SiO_2. This minimum does not reach zero, for common sense and established fact indicate that there are purely external factors which can contribute towards defects, e.g. low tapping temperatures, splashing, mould design, etc., apart from any inherent quality characteristics which the liquid steel may possess.

Referring again to Figs. 1–3, curves *B* in each were established in the same way and give the results for a combined pitting plus shelling index. These two defects were purposely plotted additively since the author has long suspected that in plates the two faults may be to some extent confused. A form of shell encountered in billets is conveniently and descriptively called ' thumb-nail ' shell. If this is flaked off a pit or depression results. This flaking off can occur more easily on plates while rolling (owing to surface extension) and the plate appears to be pitted in consequence.

It is clear that in all three periods the curves marked *B* have the same fundamental V shape: a distinctive low value for defects again coinciding with a 13–14% silica level in the slag.

In the curves marked *C* all defects except cracking have been added together (i.e. pitting, shelling, seams, laminations, blisters, etc.). Again these curves register remarkably well with the *A* and *B* curves. However, if cracking is included in the sum of ' total defects ' then the resulting curve does not nest so well. This is illustrated by results for the first period (585 casts) in Fig. 4 where a number of the points which include cracking deviate considerably from those corresponding in the *A*, *B*, and *C* curves. It is concluded that if the curves already described possess the V form when related to the silica content of the tapping slags (i.e. if the defects depend in some way on bath condition), then cracking *per se* is an independent defect. Causes other than some specific condition of the bath are responsible.

Experience suggests that this is indeed so. The effect of very fast teeming is well known and results

TABLE I

Average values June–November 1953, 585 casts

No.	Silica range, %	Average slag analysis, %					Calculated free* components (Schenck)			Calculated residuals, %		Oxygen equivalents of residuals, %		
		SiO_2	Σ Fe	MnO	P_2O_5	CaO	(SiO_2)	(FeO)	(MnO)	[Mn]	[Si]	[Mn]	[Si]	Total
2	7·01– 8·0	7·6	13·60	2·75	4·95	50·0	2·38	5·65	1·74	0·155	0·0028	0·0452	0·0031	0·0483
14	8·01– 9·0	8·5	15·9	3·18	4·81	51·0	2·68	6·13	1·85	0·151	0·0026	0·0439	0·0030	0·0469
20	9·01–10·0	9·6	15·4	2·59	5·20	51·9	3·04	5·80	1·57	0·136	0·0033	0·0396	0·0038	0·0434
52	10·01–11·0	10·5	13·6	2·99	5·56	51·65	3·40	5·68	1·66	0·147	0·0039	0·0427	0·0045	0·0472
102	11·01–12·0	11·6	12·33	3·10	6·26	52·32	3·68	5·45	1·65	0·152	0·0046	0·0442	0·0052	0·0494
92	12·01–13·0	12·6	11·9	3·37	6·21	52·7	3·96	5·20	1·72	0·166	0·0054	0·0483	0·0062	0·0545
90	13·01–14·0	13·7	10·2	3·00	6·38	52·7	4·36	4·90	1·51	0·155	0·0067	0·0452	0·0077	0·0529
111	14·01–15·0	14·6	9·7	3·25	6·62	52·2	4·67	4·89	1·56	0·160	0·0071	0·0466	0·0081	0·0547
68	15·01–16·0	15·5	8·8	3·24	6·76	51·0	5·09	4·84	1·52	0·158	0·0080	0·0460	0·0092	0·0552
27	16·01–17·0	16·4	8·4	3·17	6·84	51·8	5·46	4·71	1·48	0·158	0·0091	0·0460	0·0104	0·0564
5	17·01–18·0	17·5	8·76	3·20	6·50	50·62	5·92	4·86	1·48	0·152	0·0093	0·0442	0·0106	0·0548
2	21·01–22·0	21·4	7·8	5·61	2·00	52·1	6·21	4·15	2·02	0·244	0·0133	0·0710	0·0152	0·0862

* Note: K[Mn] = 0·502; K[Si] = 0·037

in thin-skinned ingots giving rise to cracks which later open out during rolling. Also, high sulphur contents give rise to hot shortness, and fast rolling and heavy drafting can still further exaggerate the effects due to both of these causes.

Tables I–III include the average values of the other principal slag constituents associated with the various silica ranges examined. The most noticeable trend displayed, i.e. diminution of the total iron content with increasing silica, is quite consistent with experience and is the basis of the saying ' to increase the iron in the slag one must add lime.'

Apart from the silica and total iron values, the other principal slag constituents are substantially constant, at least in each period examined. The relationship between silica and iron is not linear, as will be seen from Fig. 5 in which curves for the three periods are shown.

The broken curve is an estimated average for the three periods, values from which are used later in connection with rimming steels. The fact that all these curves are relatively smooth, except for the ' ends ' in spite of varying numbers from which the averages were obtained, suggests strongly that the relationships plotted in Figs. 1–3 are indeed valid and significant.

From the results shown in Fig. 5 it might be surmised that the total iron values (instead of silica) plotted against the defects should show curves of similar character to those in Figs. 1–3. Such a plot is illustrated in Fig. 6. Here the results for the third period were examined by classifying the iron contents of the slags and ascertaining the average silica contents together with the accompanying defects. It will be seen by comparing Figs. 3 and 6 that while there is some similarity, a single minimum defect point is not so well defined, the range of the defect values being smaller for a given range of total iron values than for an equal range of silica values. It is suggested therefore, that the total iron content alone of any slag is not such a sound criterion of metal quality as is the silica.

Further reference to Figs. 1–3 shows that in Figs. 2 and 3 the curves, particularly for shelling, have moved to a higher general level. This is of considerable significance since it indicates the effect of changes in conditions other than furnace operation. The increase in shelling can be ascribed principally to an increase in the size of moulds (area of cross-section) which pertained subsequent to the first period. General experience in other steelworks confirms this explanation.

As a matter of interest and as a further test it was thought worthwhile to separate results for duplex charges (introduced after the first period) from those for straight OH charges during the second period. Curves obtained for ' shelling plus pitting ' and ' total defects less cracking ' are given in Figs. 7 and 8, and while the curves as a whole are weaker owing to the fewer results available for each, the presence of the V shape for each type of charge is indisputable and overall average defect values are similar.

TABLE II

Average values July 1955–November 1956, 253 casts

No.	Silica range, %	Average slag analysis, %					Calculated free* components (Schenck)			Calculated residuals, %		Oxygen equivalents of residuals, %		
		SiO_2	Σ Fe	MnO	P_2O_5	CaO	(SiO_2)	(FeO)	(MnO)	[Mn]	[Si]	[Mn]	[Si]	Total
2	9·01–10·0	9·5	14·0	1·35	8·65	51·3	3·36	6·31	0·92	0·073	0·0031	0·0212	0·0036	0·0248
6	10·01–11·0	10·3	11·4	2·9	9·20	53·7	3·40	5·47	1·63	0·149	0·0042	0·0434	0·0048	0·0482
18	11·01–12·0	11·4	12·7	3·8	7·75	50·0	3·81	5·92	1·89	0·160	0·0040	0·0466	0·0046	0·0512
22	12·01–13·0	12·5	11·9	3·7	8·0	51·6	3·8	5·17	1·86	0·181	0·0053	0·0526	0·0060	0·0586
30	13·01–14·0	13·3	10·8	3·8	7·5	51·7	4·34	5·61	1·80	0·161	0·0051	0·0468	0·0058	0·0526
45	14·01–15·0	14·4	10·3	4·0	6·8	50·5	4·75	5·28	1·80	0·171	0·0063	0·0498	0·0072	0·0570
48	15·01–16·0	15·4	9·7	4·25	6·8	50·2	5·07	5·11	1·99	0·195	0·0072	0·0567	0·0082	0·0649
42	16·01–17·0	16·4	9·5	5·0	6·5	50·5	5·38	5·06	2·00	0·198	0·0078	0·0575	0·0089	0·0664
22	17·01–18·0	17·4	9·0	3·95	6·95	50·9	5·84	4·95	1·67	0·169	0·0088	0·0491	0·0101	0·0592
13	18·01–19·0	18·3	8·9	4·55	6·80	49·4	6·25	5·05	1·77	0·176	0·0091	0·0512	0·0104	0·0616
5	19·01–20·0	19·2	8·2	5·24	5·7	49·2	6·35	4·74	1·92	0·203	0·0104	0·0590	0·0119	0·0709

* Note: K[Mn] = 0·502; K[Si] = 0·037

A further consideration of the evidence suggests that defects fall to some lower level than the peaks shown in the figures when the silica is about 9–10% (although not so low as the minimum level at 13–14% silica). Slags within this lower silica range are associated with clean high-scrap/low hot-metal charges having a low total silicon content (resulting in a low total slag burden). With such charges higher ' slag iron ' values can be more easily achieved during refining. To define the extremes of the individual curves somewhat more firmly it was decided to calculate the true average total defect curve for all three periods. Figure 9*a* shows the result. Out of a total of 1 089 casts the minimum defects lie at *C* (153 casts) while ' secondary ' minima occur at 9–10% (*A*) and 15–16% silica (*X*). It must be accepted that the curve is more complex than a simple V shape.

TABLE III

Average values December 1957–February 1958, 251 casts

No.	Silica range	Average slag analysis, %			
		SiO_2	ΣFe	MnO	P_2O_5
2	6·01– 7·0	7·0	23·7	4·50	2·40
2	7·01– 8·0	7·9	24·3	3·60	2·55
3	8·01– 9·0	8·5	17·2	3·58	4·88
17	9·01–10·0	9·6	18·1	3·40	4·62
20	10·01–11·0	10·7	16·0	2·89	5·30
40	11·01–12·0	11·6	14·3	3·49	5·36
34	12·01–13·0	12·5	13·0	3·22	5·78
33	13·01–14·0	13·6	11·85	3·60	5·91
40	14·01–15·0	14·5	10·8	3·75	5·65
30	15·01–16·0	15·6	9·9	4·18	5·73
25	16·01–17·0	16·4	9·65	3·93	5·62
3	17·01–18·0	17·8	9·85	4·12	5·15
2	18·01–19·0	18·2	8·70	7·65	4·00

Preliminary conclusions

At this stage it is possible to state the following conclusions from the evidence.

(1) Both individually and collectively the classified defects existing in plate steels bear a marked complex relationship to the silica content of the tapping slag. They bear a less well defined relationship to the iron content of the slag.

(2) There appear to exist (over the range of slags examined) three minima in the defects curve, namely at 9–10%, 13–14% (lowest defects), and 15–16% silica respectively.

(3) The fact that three separate sets of data taken at intervals over some five years each reveal very similar characteristics particularly with respect to the position of the lowest defect point, confirms the validity of (1) above.

(4) Cracking appears to bear a less well defined relationship to slag composition. It is suggested therefore that this defect is ' independent.'

(5) The fact that the average of any group does not achieve a complete absence of defects indicates that the minimum level shown in Figs. 1–3 is probably limited by certain ' external ' factors, e.g. teeming conditions, pitside practice, moulds etc., which impose some constant level. Individual casts with the optimum silica value may, of course, show a complete absence of defects if these external circumstances all operate favourably. Occasional casts in the outer ranges of silica values also yield zero defects, particularly when rolled into very thin plates.

(6) Since curves for the various types of defect ' register ' with each other in all three periods examined, it is strongly suggestive that all defects, however named, have a fundamental common cause.

(7) It is concluded that steel quality is primarily a function of some condition of the bath before tapping, and the addition of deoxidizers to the ladle in order to achieve a chemical specification does not appear always to prevent the effects of this condition from occurring in the ingot.

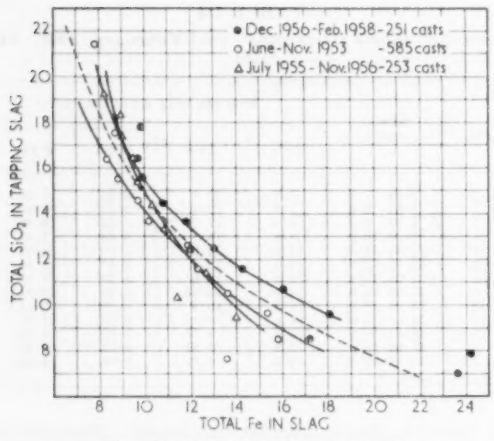
RIMMING STEELS

It is well known that there is an appreciable loss of both carbon and manganese during the rimming action in the mould and ' floaters ' high in manganese oxide frequently develop on the liquid surface before the ingot is finally capped or plated. This loss is apparent when the average analysis of the whole of a billet cross-section is compared with the killed ladle sample and is due not only to the basic C + O reaction but also to the turbulence arising therefrom causing the surface of the liquid to change continually so increasing the extent of atmospheric oxidation. To investigate this more fully the differences occurring between the ladle sample and individual randomly selected billet samples were ascertained for a number of casts of rimming steel (0·08–0·13% carbon, 0·30–0·40% manganese) with tapping-slag iron contents varying over a wide range.

Six to eight billets from each ladle were randomly sampled after lifting in bundles from the cooling bank cradle and depositing on the floor of the inspection bay. Occasionally one result out of the six or eight billets would be unduly high in carbon and manganese. This was found by sulphur printing, to indicate a segregated billet from the ingot top and the result was discarded. The general level of the results, however, indicated in the various casts differing degrees of deviation from their ladle samples.

Unfortunately for this series, no full tapping-slag analyses were available but only ' total iron ' contents. On plotting the carbon and manganese differences against the iron content of the slag the results shown in Fig. 10 were obtained. In all, some 70 casts were examined and the horizontal lines show the spread obtained for various levels of total iron. The losses range from 0·005 to 0·045%C and from 0·0 to 0·06% Mn. Such results even allowing for the apparent ' gain ' in several casts at 19%Fe in slag are not the consequence of analytical errors. The results are examined statistically in the Appendix and it becomes apparent that an average curve drawn through the bandspread has a striking resemblance in general form to the defects curve for plate steels already established. For reasons already stated (p. 220) no equivalent quantitative values for the billet casts were available.

To compare these billet curves with the final plate defect curve established in Fig. 9*a*, the iron values of the rimming steel slags were translated to probable equivalent silica values by means of the average curve *A B* shown in Fig. 5. The result obtained from a plot of the ' peak ' values is given schematically in Fig. 9*b*. The fundamental shape of both curves in Fig. 9 is


● Dec.1956-Feb.1958-251 casts
o June-Nov. 1953 -585casts
△ July 1955 - Nov.1956-253 casts
TOTAL SiO_2 IN TAPPING SLAG
TOTAL Fe IN SLAG

(The broken curve is the estimated average)

Fig. 5—Relationship between SiO_2 and total Fe in tapping slags, all periods

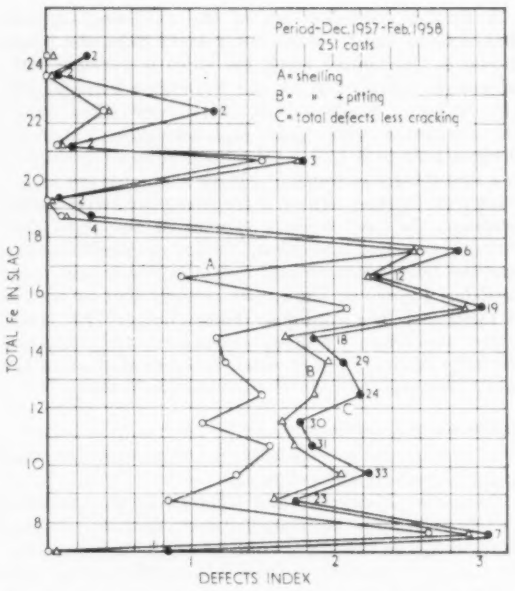


Fig. 6—Relationship between defects and total Fe in slag, December 1957–February 1958

now seen to be identical except that the rimming steel curve is shifted in relation to the silica scale in the direction of higher iron values, which is entirely consistent with the considerably lower carbon range of the rimming steels.

GENERAL DISCUSSION

While the evidence provided by the plate steels may be acceptable in the implied sense that if steel is made under slags of closely controlled and specific composition then it is the best steel (' if the slag is right the metal is right ') it is necessary to attempt some explanation of the mechanism and to provide some link between the two graphs in Figs. 9*a* and *b*.

There is obviously a narrow optimum range for silica in the tapping slag. Tables I–III show that on the average this range is accompanied by some 5–7% P_2O_5 giving a ratio of SiO_2/P_2O_5 of about 2 : 1, or a total of 19–21% ' acids'.

This latter value is generally accepted since it gives a satisfactory fluidity in conjunction with a lime content of 48–50% and consequently a basicity ratio of $2\frac{1}{2}$: 1, usually adequate to desulphurize satisfactorily. The critical silica content is less easily acceptable and an attempt to account for this constitutes the tentative theory put forward. It may be assumed that while equilibrium between slag and metal is not strictly achieved in the O H furnace since there is a continuous movement towards a lower carbon and a higher degree of oxidation, the silica in the slag will influence the silicon in the bath (cf. the reduction of silica in the acid furnace).

It has been customary in the past to consider silicon in the basic bath immediately at melting and during refining as a ' trace ' because of the environment. Accurate determination of the small quantities involved is not simple. However, it is possible if one adopts Schenck's[1] conventions of ' free ' components in slags, to use an equilibrium constant and obtain calculated values for silicon in the bath. While these values may not be absolute they do show the order of magnitude, and trends, as the silica in the slag changes.

In Tables I and II the metal/silicon values have been calculated using the ' free ' silica and total iron values (as FeO) for each of the average slag compositions classified according to their silica contents. Schenck's[2] calculations concern the evolution of a final slag composition from assumed free component values. The present work has involved the determination of the free components by trial and error from the final slag.

It is to be noted also that the free MnO values have been determined to enable the calculation of residual manganese to be carried out on a similar basis. Assuming a constant temperature of 1 600° C the calculations reveal that if slags are very high in silica (and consequently have a low total-iron content) then the residual silicon in the bath may be surprisingly high, i.e. about 0·01% while, conversely for very low-silica slags having a high iron content, then the residual silicon is as low as 0·002%. These extremes appear to be both reasonable and possible but precision analytical work at these levels is by no means easy.

A review of the slags in all tables reveals that, relative to silica, the total MnO in each is more nearly a constant. Hence the free MnO in the slags and the residual Mn in the metal is roughly constant also over the whole range.

For the series of slags in Tables I and II the [Si] and [Mn] values are plotted in Figs. 11 and 12. These contents will have a considerable effect on the activity of any oxygen present. If one compares the deoxidizing power of silicon with that of manganese and one also considers the capacity of unit weight of the former to take up oxygen when compared with unit weight of manganese, then it appears that residual silicons in the 0·002–0·008% range are indeed significant in their influence on oxygen activity.

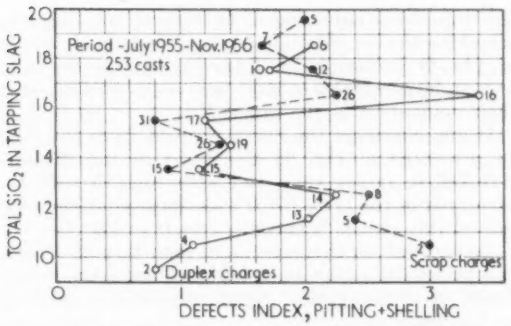


Fig. 7—Relationship between pitting plus shelling and SiO_2 for duplex and straight OH charge, July 1955–November 1956

$Si \rightarrow SiO_2$ unit weight of Si $\equiv$ 1·14 unit weight O_2
$Mn \rightarrow MnO$ „ „ „ Mn $\equiv$ 0·29 „ „ „

and in this respect the existence of a [Si] towards the lower end of the present range may be equivalent to a seriously lowered residual manganese value, a quantity in itself associated with ' quality ' by many workers.

The total oxygen equivalent of these two residuals for any slag silica value is, as seen from Tables I and II much greater than the total bath oxygen found in steels of the carbon range of the semi-killed groups and therefore without further knowledge one can only interpret relatively their effect (i.e. [Mn + Si]) on the activity of the oxygen in the bath.

Over the range of slags encountered however, the important point emerges that while the variation in this ' oxygen equivalent ' or oxygen activity increases continuously with increasing silica (top curves in Figs. 11 and 12) there is an optimum silica value above and below which there is an increase in defects.

Some confirmation of this is given by Schenck[3] who quotes a V-shaped curve by Hengstenberg similar to those in the present work, in which rejects are plotted against [FeO] before deoxidation. The fact that a critical value lies in the middle of some scale is strongly suggestive of a state of ' over oxidation ' on one side and ' under oxidation ' on the other. The mechanism that lies behind this is not at all obvious, for it is not easily apparent why there should be a critical point roughly in the middle of a series unless there is present an additional component whose behaviour is governed in some way by the critical value, so that at this point the combined effects of both are at a minimum and on either side an excess of one or the other respectively becomes harmful.

A consideration of the possibility of a gaseous component which may exert an effect by reaction with oxygen suggests that this is probably hydrogen and the relationship between them may be very similar to that found in molten copper as shown in Fig. 13 by the curve *BCD*. The determination of this curve by Allen and Hewitt[4] first led to a rational explanation of ' overpoled,' ' tough pitch,' and ' underpoled ' copper which had been fire-refined and the choice and achievement of the optimum point *C* in the curve was, in practice, evolved by trial and error many years before the theory became available and must have given the best results from the ingot as revealed by subsequent working and fabrication.

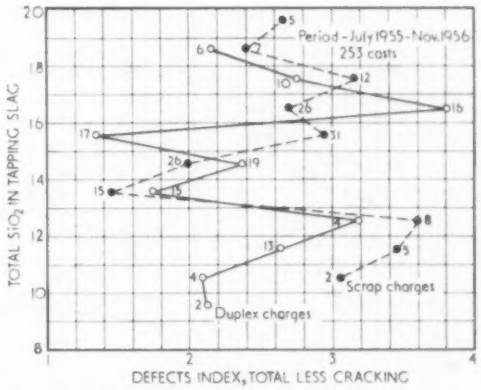


Fig. 8—Relationship between total defects (less cracking) and SiO_2 for duplex and straight OH charge, July 1955–November 1956

In the case of copper, the achievement of very low hydrogen contents by means of high oxygen contents alters the density of the solidified metal very little, but such material tends to fracture on hot or cold working owing to excessive non-metallics (Cu/Cu_2O eutectic) in spite of a high degree of soundness. Where, however, the oxygen is deficient, i.e. below the combined optimum point, then density rapidly decreases owing to increasing hydrogen and as a result of its evolution during solidification hot or cold working may again be adversely affected by the presence of unsoundness which is variously distributed depending on casting and cooling conditions.

Referring now to steel it appears that the critical silica content is indicative of a ' balance ' point (*C* in Fig. 13) between hydrogen and oxygen in the melt and on either side of this silica value defects increase sharply, as indicated by *CY* and *CB* in Fig. 9*a*. It is necessary, however, to attempt an explanation of the subsequent fall in defects in still higher and lower ranges of silica as shown by *BA* and *YX* (or *DE*) in Fig. 9*a*. The suggested explanation for this is incorporated in Fig. 13 (portions *BA* and *DE* respectively) in which it is postulated that point *B* represents maximum active oxygen solubility at a certain hydrogen level and conversely point *D* represents maximum hydrogen solubility in the melt at a certain oxygen level (not necessarily zero). Beyond these points the solubility of both oxygen and hydrogen each increase only very little as the value of the other descends to zero. It is interesting to note that a decomposition curve showing the equilibrium between H_2–H_2O mixtures and iron oxides at 772° C determined by Eastman and Evans[5] is of exactly the same form as that in Fig. 13. Only by such a postulation can one explain the changes in direction of the defects curve towards the outer limits of the slag compositions, thereby developing an M-shaped curve over the whole range.

The assumption of curve *ABCDE* in Fig. 13 as governing the relation between hydrogen and oxygen in the melt before tapping, suggests that the following holds. Point *C* represents the optimum balance between H_2 and O_2 and after partial deoxidation yields minimum defects by reducing the O_2 component of

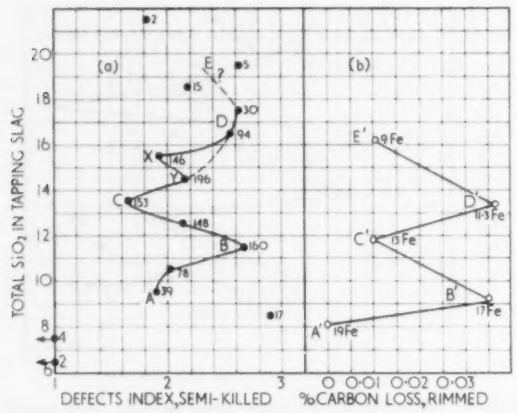


Fig. 9—(*a*) Summary curve, defects for three periods *v.* SiO_2
(*b*) Schematic curve for carbon loss, rimming steels *v.* SiO_2

the reaction. From C to B, while hydrogen does not decrease appreciably the oxygen increases rapidly and the practically fixed amount of deoxidizer used in practice does not adequately remove this oxygen therefore in overoxidized steel (to differing degrees) results, with effects as illustrated in Fig. 14. Along CB therefore, increasing defects are due to (*a*) hydrogen, plus (*b*) increasing oxygen, which may yield H_2O on solidification plus excess oxygen. From B to A however, while over-oxidation persists, the additive harmful effect of the hydrogen plus oxygen reaction reduces to near zero and therefore defects become somewhat reduced.

Conversely from C to D, the increasing defects may be due to a minimum H_2 plus O reaction (determined by the degree of deoxidation applied) on solidification but a very rapidly increasing unsoundness due to excess H_2 as D is approached yielding maximum defects at D (*see* Fig. 15).

From D to E defects are reduced somewhat again, this time by a reduction of O_2 to near zero, thereby removing the contribution to the defects made by the H_2 plus O reaction but still leaving defects due to H_2 unsoundness which are more serious in working than their equivalent in the range BA.

If one considers the curve derived from the facts as presented in Fig. 9*a* to consist of the M-shape $ABCDE$ it agrees very well with Fig. 13 with the exception of the area YXD superimposed. The location of this area is between C and D in Fig. 13.

To account for this secondary reduction in defects, two possibilities may be considered, since there is no doubt of the statistical significance of the point X in Fig. 9*a*.

(i) The area YXD is a result of deoxidation in some way. This is not very likely since one would expect the partial deoxidation applied in practice merely to shift the whole curve nearer to the H_2 axis in Fig. 13 possibly together with some overall distortion as the deoxidizer became somewhat more efficient in the higher oxygen range.

(ii) A more reasonable explanation of YXD may well be that the defects in this area have assumed a form not so easily detectable as they are elsewhere. The area lies on the excess hydrogen side of the H_2/O_2 reaction and if the surface defects occur principally as fine seams they are not apparent unless plates are descaled by pickling. Seaminess of this type is often encountered in billets and arises from small subcutaneous blowholes becoming exposed during hot working. Their presence in killed steels is indeed ascribed to hydrogen by Barraclough.[6]

It is possible that from X towards Y and D the character changes so as to render the defects more visible. This explanation, while not entirely satisfactory is considered more rational than (i) above.

It can be concluded however, that the partial deoxidation purposely applied for the production of semi-killed steels does not prevent the degree of defects encountered, from following the pattern of the H_2/O_2 relationship.

Application to rimming steels

It is necessary to consider whether the remarkably similar form of the curve for rimming steels given

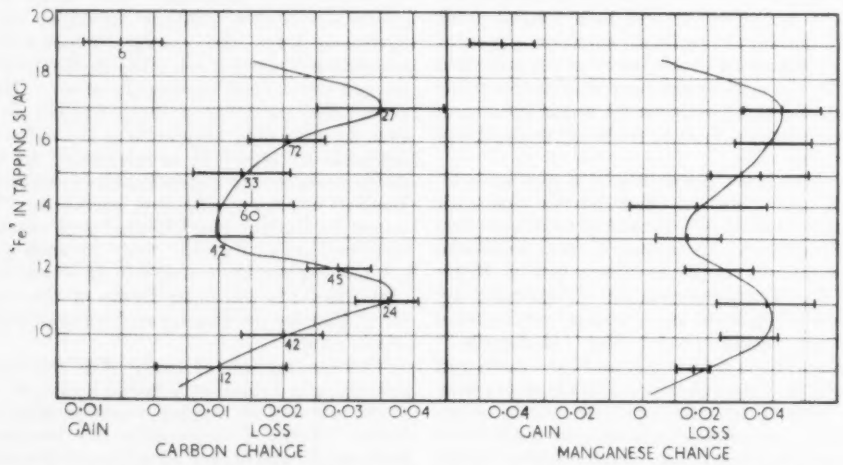


Fig. 10—(*a*) and (*b*) Spread of C and Mn, losses in rimming steels *v.* total Fe in slag

schematically in Fig. 9*b* can be explained by the postulated H_2/O_2 relationship. That hydrogen is evolved from rimming steels is well known. It is also known that such steels in the mould may display three characteristics i.e. they may rise after completion of teeming, or remain level, or they may sink.

The latter type is definitely associated with high iron slags, indicating as far as is known a considerably higher state of oxidation. This type varies considerably, for during teeming some casts may froth up initially to such an extent at the start as to leave an almost complete shell behind as subsequent cooling of the first liquid metal takes place. This characteristic is usually controlled by relatively heavy additions of aluminium to achieve a level ingot and prevent a deeply sunken top.

The type which rises after pouring is usually associated with low-iron slags. The addition of aluminium may increase the rise and conversely the addition of powdered iron oxide causes them to sink. Level rimmers do not need additions.

If one neglects the underlying C/O reaction common to all types then there is a remarkable overall similarity to the behaviour of the fire-refined copper in the underpoled, overpoled, and tough-pitch condition respectively, and *C'* in Fig. 9*b* is suggested as corresponding to *C* in Fig. 13. At this point the degree of carbon and manganese loss while rimming is basically due to the primary C/O reaction.

From *C'* to *D'* however, there is a rapid increase in the H_2 content and consequently the basic reaction is supplemented by its evolution, resulting in an increasing loss of carbon and manganese which arises

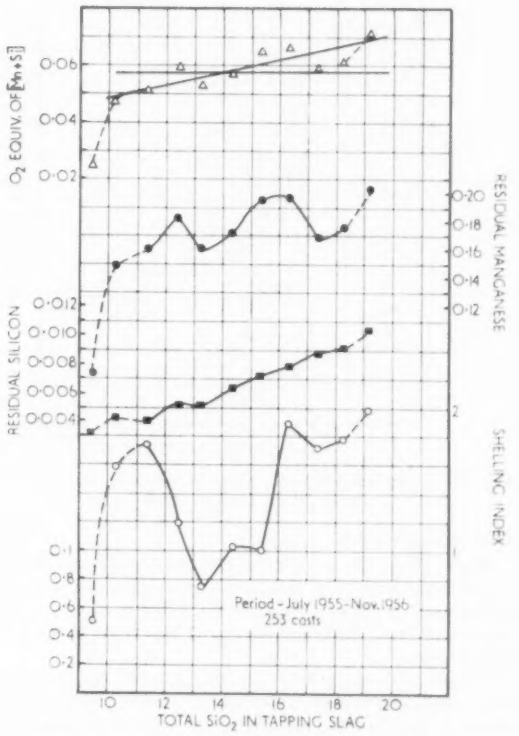


Fig. 12—As Fig. 11, July–November, 1956

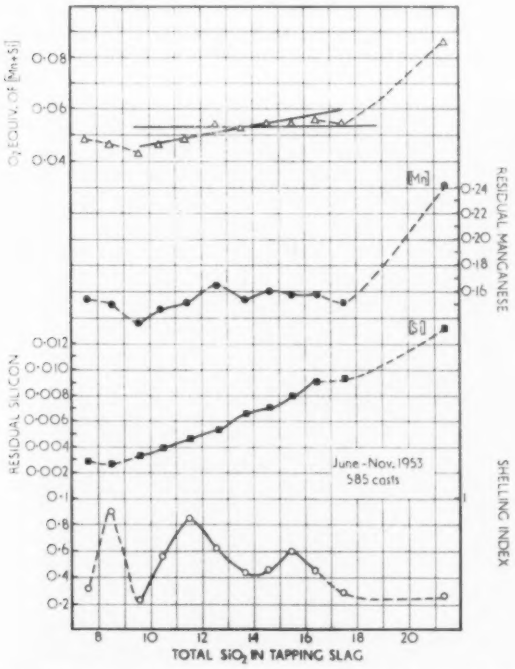


Fig. 11—Calculated residual Si and Mn *v.* shelling and SiO_2, June–November, 1953

from extra turbulence causing increased oxidation by the atmosphere during rimming. This may be accompanied by the formation of floaters and rising of the metal in the mould. The addition of aluminium over this range causes a further increase in the rise particularly if added near the ingot top and this may be due to the increase in sluggishness of the liquid near the top as a result of the local reduction of the C/O reaction intensity.

From *D'* to *E'* the rimming action decreases in intensity owing to the rapidly falling intensity of the primary C/O reaction and consequently the carbon and manganese loss again diminishes. These steels reveal considerable pearlite in the ' rim.'

A similar explanation may be given for the behaviour from *C'* to *B'*. Towards *B'* the carbon and manganese losses increase again because of an increasing intensity of the basic C/O reaction, while from *B'* to *A'* the very rapid decrease in the H_2 content again results in a diminishing total intensity of rimming compared with the range *C'B'*. It is not easy, however, to reconcile the rimmers in this latter range *B'A'* which sink, with the effect of aluminium additions on them (unless the aluminium serves to restore the rapidly diminishing intensity of the H_2/O_2 reaction by the addition of hydrogen).

While much of the foregoing is conjectural, the explanation in no way interferes with the mechanism of blowhole formation put forward by Hultgren and Phragmen.[7]

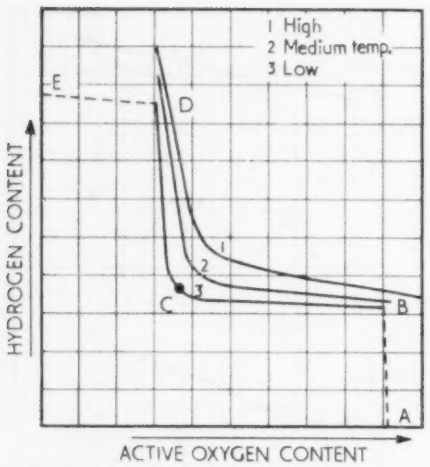


Fig. 13—Suggested relationship (schematic) between H_2 and O_2 in liquid steel

Effects in practice

Since, from the statistics, defects have been shown to increase on either side of an optimum silica value in the slag, it follows that shelling, for instance, must arise from two different causes if the theory is to be acceptable.

For low silica slags, indicative of insufficient deoxidation, shelliness might be expected to arise from metal which is dirty at the solidification point and therefore welding, or effective absorption of any splashes with and by the rising metal in the mould does not take place, particularly if temperatures are low.

For the under-oxidized state (high silica range) it may well be that the rapid drop in solubility of the hydrogen content at the melting point results in a layer of hydrogen on the metal surface, which, in contact with the atmosphere during the falling of the stream into the mould, contributes to the formation of a skin, which in its turn may also prevent welding of splashes. It may also be that the sudden reduction in solubility of an excessive hydrogen content contributes to increased splashing directly, particularly on first opening the stopper over a mould and this may explain the almost explosive 'plop' which is frequently encountered at the first impact of the stream with the stool.

This explanation has been prompted by results obtained on the effect of gases on the melting and casting of bronze.[8]

Figure 16 shows a series of small ingots, chill cast in a copper mould, of a 90–10 tin bronze. The first bar, melted and cast in an atmosphere of carbon monoxide, yielded from an uncoated mould the ingot shown on the extreme left. The bottom portion is extremely rough and this was at first thought to be due to a slight leakage of metal from the bottom of the crucible just before casting. A repetition of the experiment yielded the adjacent bar in Fig. 16 and the result was exactly similar.

Two further repetitions, this time using a mould coated with acetylene soot, gave the third and fourth bars and an explanation based on the assumption that the solubility of carbon monoxide in liquid bronze falls rapidly to a small value at the liquidus, with little further change over the freezing range, was put forward as follows. The first stream of metal from the crucible is hottest and contains at the instant of release the most gas. On contact with the cold bare mould this gas is suddenly evolved and may act as a cushion preventing the now rapidly chilled metal from reaching the sides of the mould in places. Subsequently,

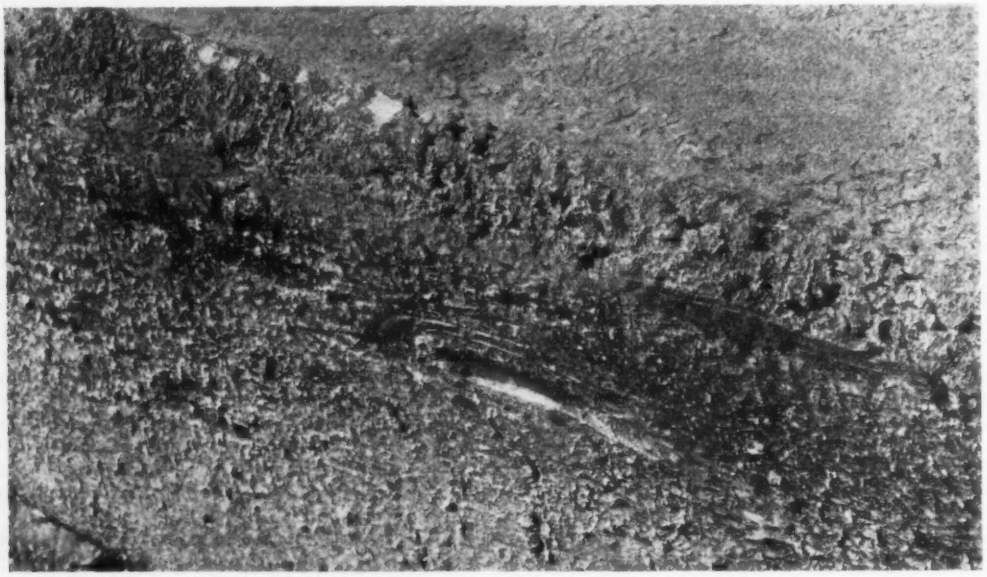


Fig. 14—Badly cracked slab

Fig. 15—Badly shelled slab

three factors are progressively coming into play:

(i) The stream is cooling somewhat and has in consequence a smaller gas content

(ii) The rate of rise of metal up the mould wall is less rapid (loss of ' head ')

(iii) The mould is becoming progressively warmer by conduction.

Thus there is a point at which the edges of the rising surface tend to remain liquid for a longer time, resulting in gas being evolved more smoothly and quietly, and soundness and ingot surface smoothness increases in consequence.

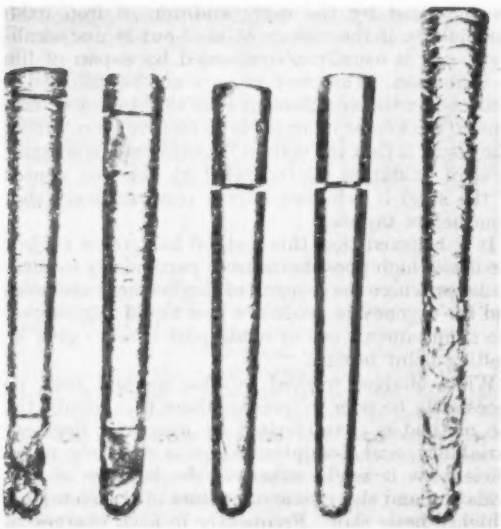


Fig. 16—Small ingots

Fig. 17—Longitudinal section of ingot melted in hydrogen atmosphere

This view is consistent with the results obtained with coated moulds. In such moulds, the initial chill on first impact of liquid metal is less severe and gas evolution down to the liquidus is more quiet, thereby yielding a smoother surface. This explanation of the function of a mould dressing is more rational than any involving ' wetability,' surface tension, viscosity etc., which has been given in the past.

It is interesting also to note that the ingot on the extreme right of Fig. 16 was melted and cast in pure hydrogen under precisely similar conditions of melting and pouring. It is obvious that hydrogen is soluble to a much greater extent than carbon monoxide and the consequent effects are much more exaggerated. Figure 17 shows a longitudinal section of this ingot.

The appearance of the bottom portions of the first two ingots poured into uncoated moulds very strongly supports the theory put forward that shelling is by no means produced exclusively by the simple oxidized splash mechanism, since splashing takes place in all top-poured moulds, and yet not all top-poured ingots are ' shelly.' Also, the pouring of ingots down a

central steel tube extending to near the bottom of the mould and allowing the tube to melt as the liquid surface rises is no guarantee that shelling will be absent. Neither is the extremely rapid pouring based upon the idea that any splashes will be more easily and rapidly absorbed by the quicker rising liquid. The author has seen some of the worst examples of shelling produced by teeming through a 4-in. nozzle from an 80-ton ladle into 15-ton slab moulds (filling time about 20 s). An acceptance of the truth of this involves two corollaries:

(i) A coated mould may help to produce a better surface in some but not all circumstances

(ii) If the steel is substantially free from a soluble gas then a mould coating is not necessary.

Item (ii) has been confirmed in practice, since an uncoated mould even when top poured does not always produce shelling.

Since there is a close correspondence in Figs. 1–3 between pitting and pitting plus shelling curves over the range of slags studied, it appears that there is a close link between the two defects, i.e. while somewhat more distinctive in character, pitting may arise from a localized form of patchy shelliness which may become detached during rolling. This effect is sometimes seen on billets (' thumb-nail ' shell) and could arise from the failure of numerous droplet splashes to weld, particularly in steels teemed at low temperatures.

No attempt has been made purposely to summarize the extensive references to hydrogen in steel available, since most of these are concerned with after effects in the solid state. However, reference may be made to a feature of the after-effects which have a bearing on the theory put forward. During the examination of some 3- and 4-in. thick plates in a killed low-carbon–high-manganese steel by supersonic tests, it was found that a peculiar irregular response was encountered on several plates, and the area defined by this type of response took the form of a strip (across the longitudinal axis of the ingot) which extended downwards to the plate end. There was no suggestion of primary segregation or V form; indeed the slabs were known to come from the bottom of the ingot. Sulphur prints through the plate thickness were normal and uniform, but it was discovered that typical hydrogen shatter cracks were responsible for the effects obtained. Further checking revealed that these cracks were present uniformly throughout up to an ingot height corresponding with the usual shelling height (the ingots were indeed ' shelly '). It is suggested therefore, that a hydrogen concentration higher than usual was present in the ingots up to a certain height. Beyond this height the mould had warmed up sufficiently to allow hydrogen to be evolved smoothly during teeming and consequently shelling ceased together with hydrogen cracks. Slow cooling after rolling eliminated this defect in subsequent casts and re-rolling of the faulty plates to thinner gauges eliminated the shatter cracks as would be expected. It is obvious that ordinary low-carbon steels are susceptible to hydrogen effects and the feature described above is no doubt responsible for many test pieces displaying a ' woody fracture ' with a poor elongation. Such test pieces in the majority of cases come from positions in the plate corresponding to the bottom of the ingot.

An additional link between the postulated theory and practice may be pointed out. General experience indicates that the ingot surfaces of alloy steels, particularly nickel steels, are usually worse than those of plain steels of the same carbon content and necessitate more dressing and rectification for similar-sized ingots. Such steels are known to be more susceptible to shatter cracks and presumably therefore possess a greater degree of solubility for hydrogen. Even low-carbon–high-manganese steels, e.g. those to Lloyds P403 rule, are known in practice to entail more dressing on an average than their ordinary mild steel equivalents. Molybdenum appears also to confer an increased degree of solubility for hydrogen both in the liquid and solid state and special precautions, usually retarded cooling at some stage of working, become necessary to avoid shatter cracks.

Finally, with reference to ' total defects ' (except for cracking) it can be seen how the level of these is influenced by such factors as the degree of sponginess of the ingot top, or depth to which objectionable segregation may run (also influenced by temperature), thereby yielding deviations from a standard as revealed by fixed cropping. It is suggested that if one could ascertain accurately the true bulk density of a whole ingot, this would provide a good measure of ' quality ' as it is likely to affect subsequent working and manipulation.

PRACTICE IN RELATION TO THEORY

An attempt has been made by means of factual evidence, to explain how the ' condition ' of a steel bath before tapping exerts an influence on quality. It would be incomplete to omit reference to methods by which the optimum condition can be secured.

A brief review of methods used in refining reveals two distinct ways in which melters work. The first, which is probably by far the most prevalent, may be described as the ' pepper and salt ' method. It is characterized by the early addition of iron oxide, particularly if the carbon at melt-out is undesirably high, and is usually accompanied by a pan of lime as a libation. This may or may not be followed by inconsequential additions of spar to thin out or more lime to thicken or more oxide to remove more carbon. The result is that the correct basicity and an adequate level of oxidation (as indicated by the iron content of the slag) is achieved only a comparatively short time before tapping.

It is believed that this method has grown up from the use of high phosphorus iron, particularly in tilting furnaces, where the removal of slag becomes necessary, and the urgency to produce a new liquid slag suggests the simultaneous use of oxide plus base to give low melting-point ferrites.

While charges worked by this method need not necessarily be poor in quality, there is no doubt that the method is characterized by a greater degree of variability, and desulphurization is certainly not as efficient as it might otherwise be because of early oxidation and short time of contact of the metal with a highly basic slag. Frequently in such charges the slag iron may show at intervals a temporary decrease

(lack of basicity) instead of a persistent steady increase. Therefore one can picture this method in the light of the theory submitted, as being similar to a pendulum swinging erratically in the path of the curve in Fig. 13, with no guarantee that the pendulum will come to rest at the optimum point at tapping. Late additions of lime made to slow down the rate of carbon drop can add appreciably to the hydrogen content of the bath, a fact well known in basic electric steelmaking.

The alternative method of attack is more systematic and controllable, and undoubtedly yields a superior steel condition with less cast-to-cast variation. Consideration of Fig. 13 shows that to eliminate hydrogen a fairly high degree of oxidation is necessary accompanied by an undisturbed boil. To achieve this one must proceed along the curve always in a constant direction, i.e. *EDC*/*B* without oscillation, aiming to arrive at point *C*. This can only be achieved by the initial adjustment of the melting slag to its correct basicity.

It is curious how many melters fail to realize that the basicity of the slag is the only controllable factor, the necessary degree of oxidation following automatically from the C/O equilibrium. This method rigorously precludes mixed feeding and/or the early addition of iron oxide until correct basicity has been secured. While the initial rate of carbon loss may be slower at first, the final rate is compensatingly faster and total time to refine is not necessarily protracted thereby. Higher bath temperatures are achieved and consequently a cleaner steel results after deoxidation. The degree of desulphurization is also enhanced (comparisons by the author reveal that this method achieves a sulphur lower by 0·01% on the average).

Many melters are reluctant to use this method since it involves a longer period of concentration while conditioning the early slag which is more severe on the roof because of its stagnancy. There is also some impatience with the slower initial rate of carbon loss.

The assessment of the correct basicity, which in turn secures the optimum silica level, can only be achieved at present by the skilful examination of slag pancakes because of the lack of sufficiently rapid methods of analysis. Herein lies the art and craftmanship of good steelmaking.

Acknowledgments

The author is indebted to the Consett Iron Co. Ltd. and Mr F. B. George, managing director, for permission to publish this paper.

He is grateful to two members of his staff, Mr R. Edmunds, whose patience with the statistics has been unlimited, and Mr C. Armstrong for his examination of the results for rimming steels.

References

1. H. Schenck: " Physical Chemistry of Steelmaking," p. 327: 1945, London, BISRA.
2. H. Schenck: *Op. cit.*, p. 337.
3. H. Schenck: *Op. cit.*, p. 497.
4. N. P. Allen and T. Hewitt: *J. Inst. Met.*, 1933, vol. 51, pp. 257–272.
5. E. D. Eastman and R. M. Evans: *J. Amer. Chem. Soc.*, 1924, vol. 46, pp. 888–903.
6. K. C. Barraclough: *Murex Rev.*, 1954, vol. 1, pp. 305–348.
7. A. Hultgren and G. Phragmen: *Trans AIME*, 1939, vol. 135, pp. 133–244.
8. T. F. Pearson and W. A. Baker: *J. Inst. Met.*, 1941, vol. 67, pp. 231–255.

APPENDIX

A statistical investigation into the existence of a functional relationship between tapping slag iron and carbon and manganese losses in rimmed steels

Null hypothesis

In any investigation of this nature the usual method is to adopt a ' null hypothesis,' i.e. to assume that in fact all the items were drawn from the same population and that the spread of results is due only to the random effects of uncontrolled variables. On the basis of this hypothesis it is then possible to calculate the probability of getting the result which has actually been obtained. If the chance of getting the observed result is extremely low one may then safely reject the null hypothesis and the existence of some degree of correlation is thus demonstrated.

Nature of the problem

The results consisted of values of carbon loss measured at ten different levels of tapping slag iron. The problem was to determine whether or not the variation of carbon loss between the levels was significant when compared with the variation of carbon loss within the levels.

The first step was to determine the grand total of squared deviations of all the items from the grand average. The total number of degrees of freedom was next found as one less than the total number of items.

The next step was to partition the total sum of squares and the total degrees of freedom into components corresponding to ' between level averages ' and ' within levels ' respectively.

To get the ' between levels ' effect it was necessary first to eliminate the ' within level ' effect. This was done by replacing each item by its own level average, thus leaving the grand total unchanged. Using the new modified items, the between levels sum of squares was calculated in an identical manner to that previously employed to determine the total sum of squares.

The between levels degrees of freedom were found directly as one less than the number of levels. The within levels sum of squares and degrees of freedom were then immediately obtainable by direct subtraction from the total sum of squares and the total degrees of freedom.

The results may be summarized as follows:

Source of variation	*Sum of squares*	*Degrees of freedom*	*Variance estimate*
Between levels	1010	9	112
Within levels	3704	349	10·6
Total	4714	358	

Hence the variance ratio is 112/10·6, i.e. about 10·6.

Snedecor's 1% level of variance ratio table gives a value of 2·3 for these degrees of freedom. This indicates a high level of significance. Assuming the null hypothesis the probability of getting the observed results is less than one in a hundred.

This means that in spite of the superimposed effects on the carbon loss of other random variables, for example variation of temperature, a functional relationship between tapping slag iron and carbon loss is still evident.

Having established the existence of a functional relationship, attention was next turned to an attempt to determine its nature. It was at once apparent that owing to the obviously complex nature of the function, any method based on the normal theory of linear regression would not be applicable. Consequently the method adopted was to try to make some estimate of the significance of each level mean so as to fix confidence limits for its value.

For each level of tapping slag iron the ' standard error of the mean ' was calculated.

This quantity is defined as

$$\sigma_m = \sigma\sqrt{n}$$

where σ_m = standard error of the mean, σ = standard deviation of the original items, and n = number of items in each level.

The probability of further sampling showing that the true mean is more than $3.\sigma/\sqrt{n}$ on either side of the level mean is only about 1%. Thus one can set up 100 to 1 confidence limits at a distance of $3\sigma_m$ on either side of the level means. These 100 to 1 confidence limits were plotted for each level of tapping slag iron and the resulting diagram gave a very good idea of the outside limits of the curve representing the relation between the tapping slag iron and the carbon loss.

The procedure was repeated using a series of values of tapping slag irons and manganese changes and an essentially similar result was obtained.

ANDREW CARNEGIE RESEARCH REPORT

The texture and mechanical properties of iron

By C. J. Ball

SYNOPSIS

An investigation has been made of the substructure developed in pure iron by deformation in tension at temperatures in the range — 77° to + 500° C. The flow stress on subsequent straining at room temperature is related to the substructure. 1565

INTRODUCTION

THIS WORK is the continuation of an investigation into the method of formation of the substructure developed in pure polycrystalline metals when deformed and the part this substructure plays in controlling the subsequent deformation.

Gay, Hirsch, Kellar, and Kelly,[1–4] in a series of papers, have shown that sub-grain formation is a feature of the deformation of a variety of metals. Kelly,[5] continuing the work, sought to explain the stress/strain curves of aluminium and iron in terms of the observed variation of sub-grain size with strain, using a theoretical relation between flow stress σ and sub-grain size t of the form $\sigma \propto t^{-\frac{1}{2}}$. It was decided to test this relationship in specimens that had been prepared under differing conditions, thus enabling an investigation to be made of the effect of other variables as well.

Aluminium was investigated first,[6] as it is the metal best suited to the X-ray microbeam technique, and it was found that the relationship is obeyed. Rather surprisingly, the angular misorientation across a sub-grain boundary does not seem to affect its strength. In iron, Hall[7] and Cracknell and Petch[8] have shown that the lower yield stress is related to the grain size by the same type of relation. If sub-grain boundaries are as strong as grain boundaries, it should be possible to extend the work of these authors to grain sizes of $\sim 1\mu$. The present paper describes an attempt to do this.

EXPERIMENTAL

Preparation of specimens

High-purity iron wire 1·5 mm in diameter (BISRA grade *AHN*5, 99·97%) was straightened by hand, recrystallized at 800° C for 4 h in a vacuum furnace, and cooled by removing to a cold part of the furnace, still *in vacuo*. This treatment gave strain-free grains of size 50μ. The wire was then cut into 4-cm lengths and hard-soldered into mild-steel end-pieces. These were heated in a special electric furnace. The holes into which the wire fitted were first filled with solder and then the cold wire, well coated with flux, was inserted. This caused the solder to solidify. As soon as the solder remelted sufficiently to allow the wire to be pushed to the bottom of the hole, the end-piece was removed from the furnace and allowed to cool. During the operation, the wire was not above 400° C for more than 10 s.

Specimens were strained in a hard-beam machine at a rate of 4×10^{-5} s^{-1} at temperatures in the range — 77° to + 500° C. High temperatures were obtained with a salt bath controlled by an Ether Transitrol to ± 2° C, low temperatures with a bath of paraffin (100° C) or dry ice in acetone (— 77° C). At each temperature specimens were strained by ~ 13%, 20%, and 28%, if this was possible without fracture.

After deformation the specimens were annealed at 500° C for 12 h *in vacuo*, and etched in the centre of the gauge length to a depth of $\sim 20\mu$ with a few drops of concentrated nitric acid.

Examination of specimens

Back-reflection photographs were taken of all specimens using beams of diameter between 50μ and 200μ with unfiltered radiation from an iron target in a Hilger microfocus X-ray set. The camera is shown in Fig. 1. The film holder and specimen are clamped to two silver-steel rods, which can be adjusted so that the beam is centrally placed and parallel to them. The collimator, a piece of lead-glass tubing, is mounted on a plate fitted with traverses, which in turn is clamped to the X-ray tube.

With this camera, which is very easy to make and operate, the specimen is about 5 cm from the focal

Manuscript received 31st March, 1958.

The author, who was formerly at the crystallographic laboratory, Cavendish Laboratory, is now at Makerere College, Kampala, Uganda.

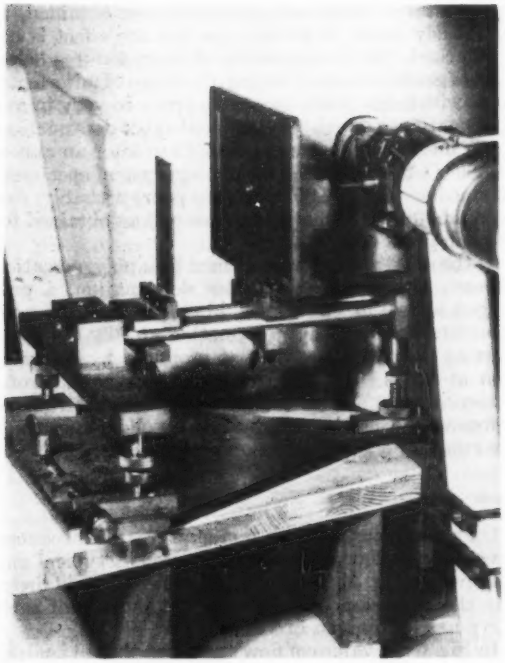


Fig. 1—The X-ray microbeam camera

spot. Exposure time is ~ 5 h with the line focus (1 mm × 0·1 mm, foreshortened to 0·1 mm square) and ~ 20 h with the point focus (0·05 mm diameter, foreshortened to 0·05 mm × 0·005 mm). The operating powers were 2·5 mA and 250 μA respectively, at 30 kV in each case. After X-ray examination, the specimens were re-strained at room temperature (20° C).

RESULTS AND DISCUSSION

Stress/strain curves

Stress/strain curves of specimens receiving the greatest strain at each temperature are shown in Figs. 2 and 3. The strain is based on the original gauge length, the stress on the instantaneous cross-sectional area. At strains slightly greater than those shown, the specimens would neck down and break, usually near the centre of the gauge length. As the

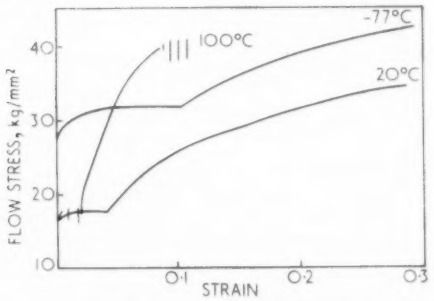


Fig. 2—Stress/strain curves of specimens strained at − 77°, + 20°, and + 100° C

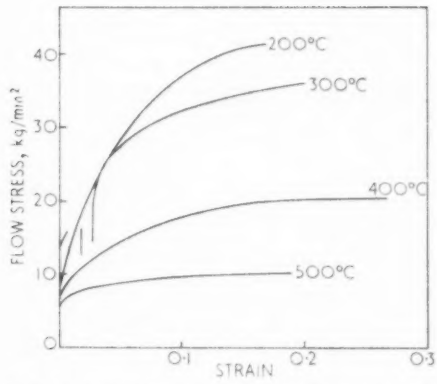


Fig. 3—Stress/strain curves of specimens strained at 200°, 300°, 400°, and 500° C

specimens were not perfectly straight at the start of the straining, the initial parts of the stress/strain curves should be disregarded. The strain each specimen received was calculated from the separation of fine scratches inscribed on the gauge length; this agreed very well with that calculated from the cross-head travel of the straining machine, except for specimens strained at 500° C, when some pulling out of the grips occurred.

The curves show clearly the effects of impurity locking of dislocations.

Annealing

The purpose of the annealing treatment at 500° C was to reduce internal strains in the specimens. Kelly[9] has shown that, in aluminium, the effect of an anneal at a somewhat lower temperature is to eliminate the background between spots on a microbeam photograph, without affecting greatly either the angular spread of an arc or the sub-grain size, though this latter is reduced slightly. Figures 4*a* and *b* are photographs of a specimen strained ~ 20% at room temperature, taken before and after receiving this treatment, and show that the effect is similar in iron, though the background is not completely eliminated. An anneal at a higher temperature or for a longer period might have achieved this, but it was essential not to recrystallize any of the specimens.

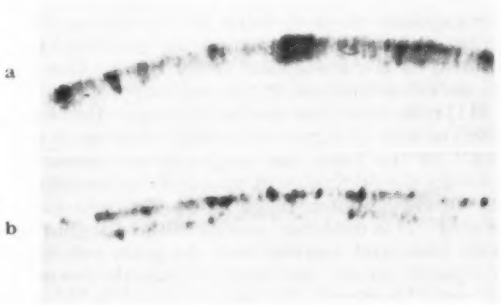


Fig. 4—Arcs from microbeam photographs of a specimen deformed ~ 20% at room temperature (*a*) as deformed, (*b*) after an anneal for 12 h at 500° C

TABLE I

Data on iron specimens

Deformation temperature, °C	Strain, %	Angular misorientations (β)	Sub-grain size (t), μ	Yield stress, kg/mm²
−77	21·7	13	1·6	28·8
,,	28·8	17	1·2	30·6
0	13·5	8	1·8	29·8
,,	20·0	16	1·7	29·0
,,	28·4	22	1·4	32·2
100	10·5	10	2·7	27·0
200	12·7	7	1·9	29·4
,,	16·8	6	2·9	30·3
300	13·5	7	2·1	24·0
,,	19·3	14	2·0	30·8
400	13·3	10	2·4	26·0
,,	20·0	15	2·4	27·1
,,	26·7	16	1·8	28·1
500	13·2	8	2·9	25·9
,,	17·8	10	2·3	...

The apparent reduction in sub-grain size is probably not a true effect; before annealing the resolution is poor, and the value obtained for the sub-grain size is almost certainly an over-estimate.

Sub-grain size and misorientations

Values of the range of misorientations in one original grain β, and sub-grain size t for all specimens are given in Table I, together with the treatments these specimens received, and their yield stress on subsequent straining at room temperature.

Measurements have been made on the {211} ring. (Methods of interpretation have been given by Hirsch and Kellar[1]). The figures quoted for β are averages of all the arcs appearing on two or three photographs.

There is some uncertainty in the determination of sub-grain size. This arises partly from the finite angular range over which a sub-grain will reflect X-rays, even after an anneal. A correction for this has been made from measurements on the shapes of spots, as described by Hirsch.[10] A more serious error arises in estimating the volume contributing to each arc. The depth of penetration is determined by the double-exposure method, using the α_1 and α_2 components of the Fe K-radiation to give the two exposures, as the absorption factor of the film for Fe K_α-radiation incident at the angle appropriate to the {211} reflection is inconveniently large. However, the surface area of a grain reflecting to an arc is not known. As the beam size employed was generally about twice the original grain size, the area contributing to an arc has been taken as equal to the mean grain area. This takes no account of the distribution of grain sizes, and assumes that the grain reflecting to any particular arc lies wholly within the beam.

The probable error in the values quoted in Table I is 10%. The values of sub-grain size obtained on deformation at room temperature are in very good agreement with those obtained by Kelly.[5] At higher temperatures larger sub-grain sizes are obtained, as previously found in aluminium, but the effect is not so marked. As in aluminium at temperatures below that of grain-boundary sliding, the range of misorientations within one grain does not appear to vary in any systematic way with the temperature of deformation.

An interesting feature is that, even after an anneal at 500° C, the resolution on photographs of specimens strained at 100° or 200° C is very poor; probably, this accounts for the rather anomalous values obtained for the sub-grain size.

If the substructure were formed by a polygonization process, either during or after deformation, a prolonged anneal at 500° C should ensure that the substructure produced by deformation at 200° C was at least as clearly defined as that produced by deformation at 20° C. That this is not the case is strong evidence in support of the view that the substructure is formed during the deformation by glide, and is not the result of a polygonization process.

Flow stress

On re-straining at room temperature, all specimens gave very similar stress/strain curves. A typical one is shown in Fig. 5. In no case was there a yield drop. The stress corresponding to the flat portion of each curve has been given in Table I.

In Fig. 6 the values of flow stress are plotted against the inverse square root of the sub-grain size. Also shown are Cracknell and Petch's[8] relation between the lower yield point and (grain size)$^{-\frac{1}{2}}$ in annealed Swedish iron of comparable purity, and the original flow stress at room temperature of the specimens used in this work, also plotted against (grain size)$^{-\frac{1}{2}}$.

Unfortunately, the scatter of the experimental points is large, and they could probably be fitted to a number of curves. What is definitely established is

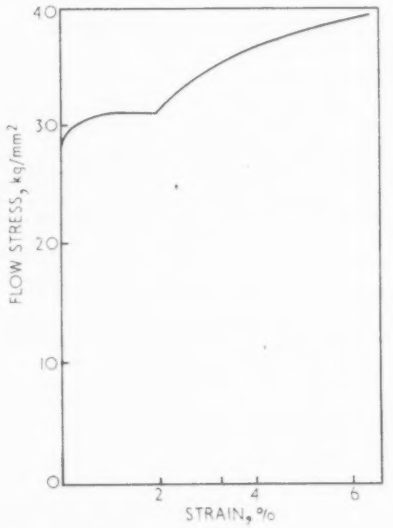


Fig. 5—Stress/strain curve of a specimen on restraining at room temperature

that they do not satisfy Cracknell and Petch's relation

$$\sigma = \sigma_o + kt^{-\frac{1}{2}}$$

with the values of the constants they obtained. However, if the one specimen that gave an anomalously large value for the sub-grain size is disregarded and the best straight line fitted to the remaining points by the method of least squares, minimizing $\Sigma(\Delta t^{-\frac{1}{2}})^2$, it is found that the intercept of this line on the σ axis is 3·5 kg/mm², very close to the value of σ_o found by Cracknell and Petch (4·3 kg/mm²). The coefficient of correlation $r = 0{\cdot}73$.

As σ_o is supposed to represent the frictional force acting on a dislocation, there is no reason to suppose that it will vary with the nature of the boundaries obstructing slip. On the other hand, k, which is a measure of the strength of the boundary, might very well be less for sub-grain boundaries, of angle $\sim 2°$, than for grain boundaries.

Cracknell and Petch take as their criterion for flow the operation of a source in the region of high stress ahead of the pile-up. The same relation can be obtained by considering the stress acting on the boundary.[11]

Consider dislocations piled up against a sub-grain boundary. The shear stress at the head of a pile-up of n dislocations under an applied shear stress τ is $n(\tau - \tau_o)$, where τ_o is a frictional force acting on each dislocation. If the criterion for flow is that this shall exceed some boundary strength τ_B we have[12]

$$n(\tau - \tau_o) = \tau_B$$

Now,

$$n = \frac{\pi L}{Gb}(\tau - \tau_o)$$

where L is the length of the pile-up, G the shear modulus and b the Bergers vector of the dislocations. Hence

$$\tau = \tau_o + \left(\frac{Gb}{\pi}\right)^{\frac{1}{2}}(\tau_B)^{\frac{1}{2}}L^{-\frac{1}{2}}$$

The tensile flow stress will be proportional to τ. If the polycrystalline specimen is homogeneously stressed, for the most favourably oriented slip system we have $t = \frac{1}{2}\sigma$. If, further, we put the length of the pile-up equal to half the sub-grain size, we get

$$\sigma = \sigma_o + 2\left(\frac{2Gb\tau_B}{\pi}\right)^{\frac{1}{2}}L^{-\frac{1}{2}}$$

Comparing this with Cracknell and Petch's equation, we see that

$$k = 2\left(\frac{2Gb\tau_B}{\pi}\right)^{\frac{1}{2}}$$

and

$$\tau_B = \frac{\pi k^2}{8G^2b}G$$

Inserting figures, we find for the grain boundaries

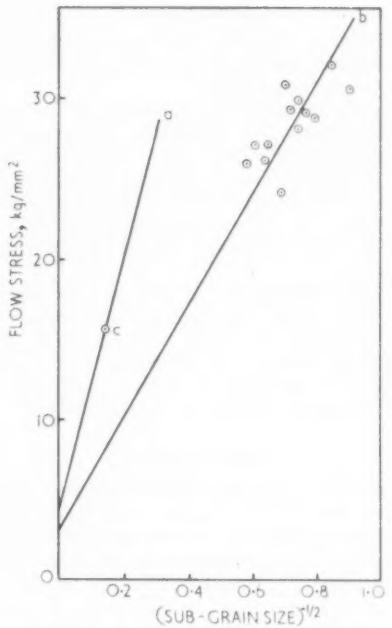
$$\tau_B = G/15$$

and for the sub-grain boundaries

$$\tau_B = G/75$$

With the same assumptions, the value of τ_B for sub-grain boundaries in aluminium was found to be $G/100$.[6] The value of $G/50$ quoted there was for pile-ups extending the full length of the sub-grain.

The mechanism of failure leading to the greatest boundary strength is nucleation of dislocations in the region ahead of a boundary. The fact that sub-grain boundaries are much weaker than grain boundaries indicates that they at least do not fail by this mechanism. The most reasonable alternative seems to be some form of elastic interaction, as already suggested for aluminium.



Line a, curve fitted to Cracknell and Petch's results
Line b, least-squares curve fitted to the present experimental points
Point c, initial flow stress of the specimens used in this work

Fig. 6—Plot of flow stress against (sub-grain size)$^{-\frac{1}{2}}$

In this connection the original stress/strain curves (Figs. 2 and 3) are of interest. The flow stresses at the end of the preliminary straining do not refer to specimens in the same mechanical condition as on re-straining, on account of the intervening anneal at 500° C. However, this would not be expected to have much effect on specimens strained at 400° or 500° C, and the increase in flow stress of these specimens on re-straining at room temperature is much greater than can be accounted for by the increase in the frictional force. This indicates that the boundaries are not nearly as effective as barriers to slip at high temperatures as they are at room temperature, unless there is some other form of stress-concentration operative.

A similar decrease in strength at high temperatures was found in aluminium. There it was suggested that the effect was due to grain-boundary sliding leading to stress-concentrations. Ke[13] has shown that, in iron, grain-boundary sliding takes place at temperatures above 400° C, and it is possible that this is the explanation of the decrease in strength found in the present work. An alternative explanation is that the strength of a sub-grain boundary is increased if the dislocations of which it is formed are locked in position by impurities. Above 400° C impurity atmospheres would boil off,[12] leaving the dislocations in the boundary free to move. Experiments with single crystals would distinguish between these two explanations.

CONCLUSIONS

The limiting sub-grain size in iron increases with increasing temperature of deformation, though not as rapidly as in aluminium.

Sub-grain formation is hindered at temperatures where impurities can follow the dislocations during deformation, confirming that sub-grain formation occurs by glide during deformation and is not the result of a subsequent process of polygonization.

The range of misorientations within one original grain does not vary markedly with temperature of deformation.

Sub-grain boundaries are not as effective barriers to slip as are grain boundaries, and their strength is further reduced at temperatures where impurity atmospheres would boil off dislocations. At room temperature their strength is very nearly the same as that of sub-grain boundaries in aluminium.

Acknowledgments

The author is greatly indebted to Professor N. F. Mott and Drs W. H. Taylor and P. B. Hirsch for their constant help and encouragement, to Mr D. H. Warrington for his assistance in designing the X-ray camera, and to BISRA for providing the iron used in this investigation. The author also wishes to express his gratitude to the Council of The Iron and Steel Institute for the award of a grant from the Andrew Carnegie Research Fund, during the tenure of which this work was carried out.

References

1. P. B. HIRSCH and J. N. KELLAR: *Acta Cryst.*, 1952, vol. 5, pp. 162–167.
2. P. GAY and A. KELLY: *Ibid.*, 1953, vol. 6, pp. 165–172.
3. *Op. cit.*, pp. 172–177.
4. P. GAY, P. B. HIRSCH, and A. KELLY: *Ibid.*, 1954, vol. 7, pp. 41–49.
5. A. KELLY: *Ibid.*, 1954, vol. 7, pp. 554–558.
6. C. J. BALL: *Phil. Mag.*, 1957, ser. 8, vol. 2, pp. 1011–1017.
7. E. O. HALL: *Proc. Phys. Soc.*, 1951, vol. 64B, pp. 747–753.
8. A. CRACKNELL and N. J. PETCH: *Acta Met.*, 1955, vol. 3, pp. 186–189.
9. A. KELLY: Ph.D. Thesis, Cambridge, 1953.
10. P. B. HIRSCH: *Acta Cryst.*, 1952, vol. 5, pp. 168–172.
11. N. J. PETCH: *JISI*, 1953, vol. 174, pp. 25–28.
12. A. H. COTTRELL: "Dislocations and Plastic Flow in Crystals," 1953, Oxford, University Press.
13. T. S. KE: *Trans AIME*, 1948, vol. 176, pp. 448–476.

The determination of trace amounts of cobalt in iron and steel and some associated materials

By the BISRA Methods of Analysis Committee

SYNOPSIS

A method is described for the determination of traces of cobalt ($< 0{\cdot}04\%$) in iron, steel, iron ore, nickel and chromium metal, and the ferro-alloys of manganese, titanium, niobium, and chromium. The procedure depends on a photometric measurement of the cobalt complex with nitroso-R-salt after a zinc oxide separation and precipitation of the cobalt with a nitroso β naphthol together with iron as 'carrier.' The reproducibility of the method is within $\pm 0{\cdot}001\%$ up to $0{\cdot}01\%$ cobalt and $\pm 0{\cdot}002\%$ up to $0{\cdot}04\%$ cobalt.

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INTRODUCTION

DURING the last few years there has been an increasing demand for cobalt determinations on steels required for certain Atomic Energy Authority applications where maximum specification limits of $0{\cdot}02\%$ and, in some cases, $0{\cdot}01\%$ of the element have to be met.

None of the conventional procedures has the required sensitivity for accurate determinations in trace ranges and it was obvious that a specialized analytical technique would have to be developed to meet this particular requirement. It was also desirable that the method to be developed for steel should be adaptable to the analysis of steelmaking materials, ores, ferro-alloys, etc. as the ability to make steel conforming to specified low cobalt limits is dependent on the selection of suitable raw materials.

The experimental work, on which the present report was based, was carried out by the Highly Alloyed Steels and Ferro-Alloys Analysis Sub-committee.*

Paper MG/D/173/58 of the Metallurgy (General) Division of the British Iron and Steel Research Association, received on 15th September, 1958.

* The constitution of the Sub-committee at 31st March 1958, was as follows: Mr B. Bagshawe (*Chairman*), Brown-Firth Research Laboratories; Mr C. D. Atkinson, Sheffield Testing Works, Ltd.; Mr L. E. Gardner, Edgar Allen and Co. Ltd.; Mr S. Harrison, Kayser Ellison and Co. Ltd.; Mr J. D. Hill, The Bragg Laboratory, N.O.I.E.; Mr G. M. Holmes, London and Scandinavian Metallurgical Co. Ltd.; Mr L. Kidman, English Steel Corporation, Ltd.; Mr G. Murray, Brown Bayley Steels, Ltd.; Mr R. T. Postlethwaite, Samuel Fox and Co. Ltd.; Mr L. N. Taylor, Samuel Osborn and Co. Ltd.; Mr J. L. West, Hadfields Ltd.; Mr W. Wright, Permanent Magnet Association.

EXPERIMENTAL INVESTIGATION

Consideration was at first given to the possibility of improving the sensitivity of the existing British Standard method B.S. 1121: Part 30: 1954. This is a direct absorptiometric method depending on the reddish-brown colour produced by reaction between cobalt and nitroso–R–salt in buffered solution, interfering complexes of other metals, e.g. iron, being then destroyed by treatment with nitric acid. This method is satisfactory at cobalt ranges up to 12%, but it was not intended for determinations of trace amounts and there are several factors which limit the potential accuracy of the procedure for this purpose.

In B.S. 1121: Part 30: 1954 the 4-cm cell covers a range of 0–0·8% cobalt. For the present purpose, i.e. trace amounts of cobalt, a suitable range would be 0–0·04% cobalt, and to achieve this with B.S. 1121: Part 30: 1954, the sample weight would need to be increased twentyfold, i.e. 0·5–10 g. Tests have shown that large concentrations of iron cannot be tolerated, as the iron complex with nitroso–R–salt cannot then be completely destroyed by boiling with nitric acid and the sensitivity of the cobalt reaction is also impaired with increasing iron content. The alternative would be to remove all or most of the iron. Tests were therefore made with a modified procedure in which iron was removed by selective extraction with amyl acetate. Whilst this was satisfactory as a means of eliminating iron interference, the procedure failed on alloy steels owing to serious interference from nickel and to a lesser extent from chromium.

Nickel is known to react with nitroso–R–salt but it does not apparently form a coloured complex with the reagent. B.S. 1121: Part 30: 1954 provides for up to 5% nickel without interference but above this, additional reagent is required at the rate of 1 ml of the 0·3% solution for each 0·5 mg of nickel in the final aliquot. It follows therefore that in scaling up the weight basis twentyfold, as was done in the amyl acetate modification, nickel interference takes effect at about 0·25% and any useful extension of the non-interference range by further additions of reagent then becomes impracticable.

Copper also is known to consume reagent and in B.S. 1121: Part 30: 1954, 2% copper is the limit for the normal reagent addition. Whilst the effect of copper has not been further examined for the purpose of the present work, an interference limit of about 0·1% copper could be expected, when the sample weight is increased twentyfold.

From the foregoing it was concluded that it would be necessary to remove most of the iron, chromium, nickel, and copper as an essential preliminary to the successful application of the nitroso–R–salt reaction. At this stage some consideration was given to the possibility of making use of alternative procedures, e.g. the reaction with tetraphenylarsonium chloride,[1, 2, 3] determination as thiocyanate after extraction with methyl isobutyl ketone[4] or as the coloured complex with β nitroso α naphthol after extraction with chloroform.[5, 6] It was decided, however, to investigate fully the possibilities of applying the nitroso–R–salt reaction before giving further attention to these alternative methods.

A method was drafted in which iron was extracted with amyl acetate, chromium was volatilized as chromyl chloride from a fuming perchloric acid solution, and cobalt precipitated with α nitroso β naphthol from a buffered acetate solution. After filtration the cobalt complex was decomposed by wet oxidation with nitric and phosphoric acids and the determination completed photometrically with nitroso–R–salt. The results obtained, however, were very inconsistent.

It was considered that at least four factors might be contributing to the poor performance of the method: (*a*) interference from small but variable amounts of residual iron from the amyl acetate separation; (*b*) incomplete precipitation of cobalt with α nitroso β naphthol due to the extremely low cobalt concentration of the solution and the absence of sufficient nucleus to 'gather' the precipitate; (*c*) interference from copper which is co-precipitated with α nitroso β naphthol; (*d*) possible interference from nickel which may not be eliminated completely when the α nitroso β naphthol precipitation is carried out in buffered acetate solution.

These points were met in a new procedure[7] in which iron and chromium were removed by zinc oxide hydrolysis and cobalt precipitated with α nitroso β naphthol from dilute hydrochloric acid solution together with 5 mg of added iron to act as carrier. The zinc oxide separation has the advantage that both iron and chromium are completely removed in one operation, and most of the copper is also co-precipitated with the hydroxides. If vanadium is present much of this is also eliminated by the zinc oxide separation and tests by one member showed no interference from vanadium when up to 5% was present. As precisely 5 mg of iron is subsequently added as carrier for the cobalt α nitroso β naphthol complex the final iron concentration is constant and the photometer calibration for the nitroso–R–salt reaction can be made with the same amount of iron present.

Very satisfactory results were obtained in the first trials of this method and only one or two minor alterations of detail were made for the final draft. Precipitation with α nitroso β naphthol at boiling point was studied as the temperature generally recommended for this precipitation is 70–80° C. After comparative tests had indicated no significant difference in results, it was decided to recommend the higher temperature since it was easier to apply, but to specify that the solution should be removed from the source of heat before adding the reagent in order to minimize frothing.

It was decided that the investigation should not be extended to the examination of methods using tetraphenylarsonium chloride and β nitroso α naphthol, as the required sensitivity had been obtained in the procedure described above. No comments can therefore be made on the alternative reagents.

APPLICATION OF THE RECOMMENDED METHOD

The recommended method (*see* Appendix) was applied to a representative selection of steels with compositions shown in Table I. The results obtained on these steels are shown in Table II.

TABLE I

Approximate composition of samples

Sample no.	Element, %											
	C	Mn	Si	Ni	Cr	V	Mo	Cu	Ti	Sn	Others	Material
MGS/64	0·34										S 0·05	Mild steel
MGS/97	0·35	0·50	0·32	1·49	1·01		0·21					Ni–Cr steel
MGS/182	0·04	0·75	0·6	0·24	21						Al 0·005	FI 20
MGS/275	0·23	0·47	0·30	0·01$_5$	0·04$_2$	< 0·005	0·19	0·01	0·00$_8$	0·11		Mild steel SS11
MGS/277	0·15	0·48	0·19	0·03	0·07$_4$	0·04$_8$	0·04$_3$	0·06$_2$	0·07$_0$	0·06$_5$		Mild steel SS13
MGS/279	0·19	0·48	0·19	0·18	0·10	0·05$_2$	< 0·01	0·12$_4$	0·005$_5$	0·01$_4$		Mild steel SS16
MGS/302		4 ppm	2 ppm	2 ppm				1 ppm				Pure iron sponge
MGS/304	0·02	< 0·01	0·43	< 0·02	< 0·02		< 0·02					Swedish iron (remelted with ferrosilicon addition)
MGS/305				8·0	18·0				0·5			18–8 stainless steel (trace cobalt type)
MGS/310		0·02	0·25	4·10	0·20	0·46	0·01	0·11		0·004		Low-alloy steel BCS/252
MGS/311		1·21	0·13	0·18	2·34	0·36		0·23		0·012		Low-alloy steel BCS/256

The method was next applied to a variety of steelmaking ferro-alloys and raw materials, and the results obtained are shown in Table III.

The ferrotitanium and ferroniobium alloys required a modified decomposition treatment and this is detailed in the notes to the method (*see* Appendix). High-carbon ferro–chrome may also require a modified solution treatment. Apart from these, no other changes were found necessary in applying the method to the materials specified.

An independent confirmation of the accuracy of the recommended method is provided by Table IV which compares the results on a series of low-alloy British Chemical Standard steels obtained using the recommended method with those obtained by Smales *et al.*[8] using a radioactivation technique.

CONCLUSIONS

The method recommended as a result of this investigation is satisfactory for the determination of traces of cobalt (0–0·04%) in a wide range of iron and steels and also for the ferro-alloys of manganese, titanium, niobium and chromium, chromium metal, nickel, and iron ore. The reproducibility of the method is within ± 0·001% up to 0·01% cobalt and ± 0·002% up to 0·04% cobalt.

The method has been recommended for adoption as a British Standard.

References

1. H. E. Affsprung, N. A. Barnes, and H. A. Potratz: *Anal. Chem.*, 1951, vol. 23, pp. 1 680–1 683.
2. L. P. Pepkowitz and J. L. Marley: *Ibid.*, 1955, vol. 27, pp. 1 330–1 331.
3. H. A. Potratz and J. M. Rosen: *Ibid.*, 1949, vol. 21, pp. 1 276–1 279.
4. R. H. A. Crawley: Private Communication.
5. A. Claasen and A. Daamen: *Anal. Chim. Acta*, 1955, vol. 12, pp. 547–553.
6. R. C. Chirnside: Private Communication.
7. J. R. Rait and J. L. West: *Chem. Ind.*, 1957, Sept. 7, p. 1 204.
8. A. A. Smales, D. Mapper, and A. J. Wood: *Analyst*, 1957, vol. 82 pp. 75–88.

APPENDIX

Recommended method

Reagents required

Ferric chloride—Dissolve 0·5 g of pure iron in 20 ml of hydrochloric acid (sp.gr. 1·16–1·18) oxidize with nitric acid (sp.gr. 1·42), cool, and dilute to 100 ml.

Hydrochloric acid (10% *v/v*)—Dilute 100 ml of hydrochloric acid (sp.gr. 1·16–1·18) to 1 l.

Nitric acid (50% *v/v*)—Dilute 500 ml of nitric acid (sp.gr. 1·42) to 1 l.

α nitroso β naphthol—Dissolve 1 g of α nitroso β naphthol in 15 ml glacial acetic acid. Filter before use.

Nitroso–R–salt (0·3% *w/v*)—Dissolve 0·3 g of nitroso–R–salt in water and dilute to 100 ml.

Phosphoric–sulphuric acid (15/15% *v/v*)—To 600 ml of water add 150 ml phosphoric acid (sp.gr. 1·75) and 150 ml of sulphuric acid (sp.gr. 1·84). Cool and dilute to 1 l.

Sodium acetate (50% *w/v*)—Dissolve 500 g of sodium acetate ($CH_3.COONa.3H_2O$) in water and dilute to 1 l.

Zinc oxide suspension—Add 50 g of finely powdered zinc oxide to 200 ml of water and stir or shake until a smooth cream is obtained. The suspension should be stirred immediately before use and also between additions during use.

Procedure

Weigh 2·5 g of sample (Note 1) and transfer to a 650-ml conical beaker, dissolve in 20 ml hydrochloric acid (sp.gr. 1·16–1·18) (Note 2) and oxidize with a minimum amount of nitric acid (sp.gr. 1·42). Evaporate to about 10 ml. Add 30 ml of water, cool, and dilute to about 300 ml.

Add zinc oxide suspension in small amounts with intermittent shaking until the solution is neutralized and a faint permanent precipitate of iron group hydroxides is obtained (Note 3). Then make a final addition of 10 ml of zinc oxide suspension to ensure the complete precipitation of these hydroxides (Note 4). Transfer to a 500-ml graduated flask, dilute to the mark with water, mix and allow to stand for 5 min.

Filter through a dry fluted 24-cm Whatman No. 541 paper and after discarding the first few ml of the clear filtrate, collect a 250-ml aliquot. Transfer to a 650-ml

TABLE II

Determination of cobalt in a series of iron and steel samples using the recommended method

Analyst	Cobalt, %										
	MGS/64	MGS/97	MGS/182	MGS/275	MGS/277	MGS/279	MGS/302	MGS/304	MGS/305	MGS/310	MGS/311
1	0·012$_0$	0·018$_5$	0·027$_5$	0·013$_0$	0·023	0·026$_0$	< 0·001	0·003$_5$	0·004$_0$	0·042	0·032$_0$
2	0·011$_5$	0·017$_5$	0·027$_0$	0·012$_5$	0·020	...	< 0·001	0·003$_0$	0·003$_0$	0·040	0·031$_5$
3	0·011$_5$	0·016$_0$	0·027$_0$	0·011$_5$	0·020	0·026$_5$	n.d.	0·003$_5$	0·002$_5$	0·041	0·031$_5$
4	0·012$_0$	0·019$_0$	0·026$_0$	0·013$_0$	0·021	0·027$_0$	< 0·001	0·003$_0$	0·003$_0$	0·040	0·032$_0$
5	0·010$_0$	0·016$_0$	0·025	0·013	0·019	0·024	< 0·001	...	0·002$_5$	0·037	0·029
6	0·012$_0$	0·017$_0$	0·027$_0$	0·013$_5$	0·021	0·027$_5$	< 0·001	0·003$_5$	0·003$_5$	0·040	0·031$_0$
7	0·011$_0$	0·016$_0$	0·026$_0$	0·013$_0$	0·021	0·027$_0$	< 0·001	0·003$_5$	0·003$_0$	0·038	0·029$_5$
8	0·011$_5$	0·017$_0$	0·027$_0$	0·013$_0$	0·021	0·027$_0$	< 0·001	0·003$_0$	0·003$_0$	0·040	0·031$_5$
9	0·011$_5$	0·016$_0$	0·026$_0$	0·012$_5$	0·020	0·026$_5$	n.d.	0·003$_0$	0·002$_5$	0·038	0·031$_5$
10	0·011$_5$	0·016$_5$	0·026$_5$	0·013$_0$	0·021	0·028$_0$	< 0·001	0·003$_5$	0·003$_5$	0·040	0·029$_5$
11	0·011$_5$	0·017$_0$	0·026$_5$	0·012$_5$	0·021	0·026$_5$	< 0·001	0·003$_5$	0·002$_5$	0·039$_5$	0·030$_0$
Average	0·011$_5$	0·017$_0$	0·026$_5$	0·012$_5$	0·021	0·027$_0$	< 0·001	0·003$_5$	0·003$_0$	0·040	0·031$_0$
Range	0·010–0·012	0·016–0·019	0·025–0·027	0·011–0·013$_5$	0·019–0·023	0·024–0·026	...	0·003–0·003$_5$	0·002$_5$–0·004	0·037–0·042	0·029–0·032

n.d. = not detected

conical beaker, add 10 ml of hydrochloric acid (sp.gr. 1·16–1·18) and 1 ml of ferric chloride solution and heat to boiling. Remove from the source of heat and add 15 ml of freshly prepared α nitroso β naphthol solution, add a little paper pulp. Stand for 3 h or preferably overnight.

Filter through a paper pulp pad, wash three times with hydrochloric acid (10%) and finally three times with cold water. Transfer the filter and contents to a platinum dish, carefully dry the paper and ignite to the oxide.

Dissolve the residue with 10 ml of hydrochloric acid (sp.gr. 1·16–1·18), add 5 ml phosphoric–sulphuric acid (15/15%) and evaporate to fumes. Cool and add 5 ml of water. Heat to boiling, cool and transfer to a 25-ml graduated flask, dilute to the mark with water and mix thoroughly.

Transfer two 10-ml aliquots *A* and *B* into 50-ml graduated flasks and continue as described below. It is recommended that all additions are made from burettes or pipettes.

Test solution—Add 10 ml nitroso–R–salt solution (0·3%) mix and add 10 ml of sodium acetate solution (50%). Mix well and stand for 5 min at room temperature. Add 10 ml of nitric acid (50%), mix well and stand for a further 5 min at room temperature. Dilute to 50 ml with water.

Compensating solution—Add 10 ml of sodium acetate

TABLE III

Determination of cobalt in a selection of steelmaking materials

Analyst	Cobalt, %							
	MGS/83	MGS/283	MGS/314	MGS/321	MGS/322	MGS/324	MGS/328	MGS/329
	Sproxton iron ore	Ferro-manganese (76·78% Mn)	Chromium metal	Low carbon ferrochrome (70% Cr)	Mond nickel	Hematite iron	Ferro niobium	Ferro titanium (38·39% Ti)
1	0·006	0·026	< 0·001	0·047	< 0·001	0·006	0·003	0·019
2	...	0·025	...	...	...	...	0·003	0·018
3	0·006	0·023	...	0·047	< 0·001	0·006	0·002	0·017
4	0·006	0·025	< 0·001	0·044	0·002	0·006	0·003	0·020
5	0·006	...	< 0·001	0·045	...	0·006	0·002	0·017
6	0·005	0·025	n.d.	0·045	< 0·001	0·006	0·003	0·019
7	0·005	0·025	< 0·001	0·043	0·001	0·006	0·003	0·019
8	0·006	0·024	< 0·001	0·044	< 0·001	0·006	0·003	0·019
9	0·005	0·024	< 0·001	0·045	< 0·001	0·006	0·003	0·019
10	0·005	0·023	n.d.	0·044	< 0·001	0·005	0·003	0·019
11	0·005	0·025	< 0·001	0·043	< 0·001	0·006	0·003	0·019
Average	0·005$_0$	0·025	< 0·001	0·045	< 0·001	0·006	0·003	0·019
Range	0·005–0·006	0·023–0·026	...	0·043–0·047	< 0·001–0·002	0·005–0·006	0·002–0·003	0·017–0·020

n.d. = not detected

TABLE IV

Comparison of results by the recommended method with radioactivation results obtained by Smales[8]

Sample no.	Cobalt, %	
	Recommended method	Radioactivation (Smales)
BCS 252	0·040	0·043
,, 253	0·032	0·031
,, 254	0·029	0·027
,, 255	0·020	0·019
,, 256	0·031	0·031
,, 257	0·023	0·023
,, 258	0·029	0·028

solution (50%), 10 ml of nitric acid (50%), and dilute to 50 ml with water.

Measure the optical density of each solution at a wavelength in the range 560–580 mμ. If a filter photometer of the balanced two-cell type is used, the filter combination should conform as closely as possible to the above waveband. The following conditions have been found suitable: mercury-vapour lamp; Kodak 5, Ilford 605, or Wratten 74 filters used together with H503 filters; 2- or 4-cm cells.

Determine the blank value of the reagents concurrently with the test determination and make the appropriate correction.

Calibration

Standard cobalt solution A—Dissolve 0·1 g of pure cobalt sheet in 10 ml of nitric acid (50%) and dilute to 1 l.

Standard cobalt solutions B—Dilute 100 ml of solution *A* to 1 l. 1 ml of this solution contains 0·01 mg cobalt.

Transfer ten 5-mg lots of cobalt-free iron (i.e. 1 ml ferric chloride solution) to 250-ml conical beakers and add 0·0 ml, 2·5 ml, 5·0 ml, 10·0 ml, 12·5 ml, 15·0 ml, 17·5 ml, 20·0 ml, and 22·5 ml of standard cobalt solution *B*. Add 5 ml of phosphoric–sulphuric acid (15/15%) oxidize with 1 drop of nitric acid (sp.gr. 1·42), evaporate to fumes and proceed as described in the procedure. Prepare a calibration graph.

4-cm cell range 0–0·02% Co
2-cm cell range 0–0·04% Co

Notes

1. Samples should be prepared with cobalt-free cutting tools.

2. (*a*) For ferro-titanium dissolve the sample in a mixture of 20 ml of sulphuric acid (50% v/v), 10 ml of hydrochloric acid (sp.gr. 1·16–1·18), and 5 ml of nitric acid (sp.gr. 1·42). When solvent action ceases, evaporate to fuming, cool, and redissolve the sulphates with 30 ml of water. Add a few drops of nitric acid (sp.gr. 1·42) and boil. Cool, dilute to 300 ml. Continue as from paragraph 2 of the procedure.

(*b*) For ferroniobium transfer the weighed sample to a platinum dish, provided with a cover. Add 10 ml of hydrofluoric acid and make dropwise additions of nitric acid (sp.gr. 1·42) until the sample is dissolved. Add 30 ml of sulphuric acid (50% v/v) and evaporate to fuming to expel fluorides. Cool, transfer to a 650-ml conical beaker, add 10 ml of hydrochloric acid (sp.gr. 1·16–1·18), dilute to 300 ml and boil to dissolve soluble salts. Cool, and continue as from paragraph 2 of the procedure.

(*c*) For high-carbon ferrochrome dissolve the sample as far as possible by digestion with 30 ml of sulphuric acid (50% v/v). Then add 15 ml of hydrochloric acid (sp.gr. 1·16–1·18) and heat until solvent action ceases. Evaporate to incipient fuming, cool, and dilute with 30 ml of water. Boil and oxidize with nitric acid (sp.gr. 1·42). Boil to remove nitrous fumes and dilute to 300 ml. Continue from paragraph 2 of the procedure.

3. Cool the solution if necessary before making the final addition of zinc oxide.

4. Complete neutralization is indicated by a definite change from a clear, dark-coloured solution to a turbid brown solution due to the precipitation of hydroxides. The addition of 10 ml excess of the zinc oxide suspension causes the brown precipitate to appear lighter in colour and the supernatant liquid assumes a milky-white appearance.

The influence of sulphur and oxygen in causing red-shortness in steel

By A. Josefsson, J. Koeneman, and G. Lagerberg

SYNOPSIS

The influence of thermal history on red-shortness in steels containing 0·02–0·08%S, < 0·01–0·09%Mn, and high carbon contents (up to 0·8%C) was studied by means of impact-testing. Sulphur was found to cause red-shortness in two distinct ways: (*a*) by hardening the austenite, and (*b*) by forming intergranular sulphide precipitates. Both phenomena lead to intercrystalline fracture and one or both may be eliminated by heat-treatment, as is demonstrated for a steel with 0·076%S. Manganese counteracts red-shortness by (*a*) reducing the sulphur solubility in austenite and hence its hardening potentiality, and (*b*) by preventing the formation of embrittling grain-boundary sulphides. Tests with iron low in sulphur and manganese and containing up to 0·035%O indicated that oxygen alone does not induce red-shortness. 1543

INTRODUCTION

BY RED-SHORTNESS IN STEEL is meant a tendency to brittle fracture during hot-working at temperatures round 900° C. This phenomenon has long been

Manuscript received on 18th February, 1958.

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attributed to sulphur. Oxygen has often been considered to exert a similar influence or at least to enhance the effect of sulphur. It is well known that manganese counteracts red-shortness.

According to a common explanation red-shortness results from intergranular sulphide films which reduce the cohesion at grain boundaries. Reference is often made to the low eutectic temperature of the Fe–S system (988° C).[1] However, since there is no obvious change in the brittle behaviour at this temperature the liquid state of the films cannot be decisive in causing the brittleness.

Manganese is assumed to counteract red-shortness by raising the solidification temperature for the sulphide melt[2] thus decreasing the tendency to liquid-film formation.

At relatively high sulphur and low manganese contents, more or less continuous networks of sulphide outlining the austenite grain boundaries may be observed in the microstructure.[3] However, the brittleness may still be pronounced, even when the sulphur content is so low that films are absent. Hence, it appears that the film theory does not provide a sufficient explanation for the red-shortness phenomenon.

Oxygen is sometimes supposed to contribute to red-shortness by means of its lowering the eutectic temperature. The formation of oxide inclusions containing manganese has also been considered. This process would neutralize the counteracting effect of manganese and render the steel more red-short.[4]

Previous investigations[5–10] have dealt mainly with the dependence of red-shortness on the sulphur and oxygen contents versus manganese. In manganese-free steels red-shortness was not observed below 0·010%S[5, 8] but was pronounced at 0·020%S.[5, 9] These steels contained considerable amounts of oxygen. Hultgren and Herrlander,[11] however, found red-shortness cracks at a sulphur content as low as 0·008%. These cracks occurred not only upon deforming in the γ-range but also when the deformation was made well below Ac_3. In this case they seemed to follow ferrite grain boundaries. It was suggested that the harmful sulphur could be present in solid solution or as a submicroscopic precipitate of sulphide. Anderson *et al.*[6] found that the concentration of manganese necessary to prevent red-shortness, at probably low oxygen levels, could be represented by the empirical formula

$$(\%\mathrm{Mn}) = 1{\cdot}25(\%\mathrm{S}) + 0{\cdot}03.$$

Kalling[7] pointed out that the thermal history had a marked influence on red-shortness; the brittleness was more pronounced after cooling from a high temperature to the testing temperature than after direct heating to the latter.

Some of the discrepancies that can be found in the red-shortness literature are probably due to differing testing methods. In the forging test often used, the reproducibility of the experimental conditions depends on the skill and judgment of the experimenter. In this test the sample is usually heated to some high temperature (e.g. 1 100–1 130°C [8, 9]) and allowed to cool while being repeatedly bent 90° over an anvil by means of rapid strokes with a hammer. Fracture occurs when the temperature reaches the 'red-short temperature range.' In some cases more well defined testing conditions have been attempted. Thus Fell[8] used Charpy impact tests in the pertinent temperature range the results of which agreed well with forging tests. Anderson *et al.*[5] performed torsion tests at high temperatures and used the number of revolutions before fracture as a measure of the degree of red-shortness. One may object that in this case not only red-shortness but also a local deformation caused by some inhomogeneity or a low degree of strain hardening may result in a low number of revolutions.[23] A special red-shortness test was suggested by Görrissen[10] according to which a notch was pressed into the sample at red heat and then widened with a special tool at 800° C. The degree of red-shortness was judged by observing the cracks at the bottom of the notch. This rather complicated procedure hardly looks promising for well defined testing conditions.

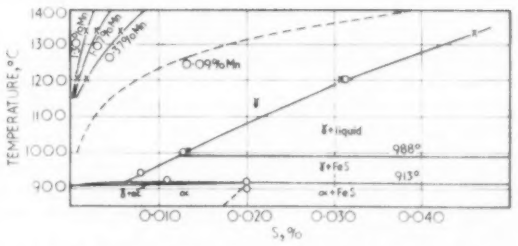


Fig. 1—Part of Fe–S phase diagram including solubility curves for sulphur in austenite with 1·30, 1·07, 0·37, and 0·09%Mn. The curve for 0·09%Mn is computed from data given in ref. 12, assuming equilibrium with pure MnS

For the study of red-shortness the phase diagrams may serve as a theoretical background. The system Fe–S has been investigated by Rosenqvist and Dunicz[1] and by Turkdogan, Ignatowicz, and Pearson.[12] The latter authors also studied the influence of manganese on the solubility of sulphur in austenite. Figure 1 shows the relevant part of the Fe–S diagram and also solubility curves for sulphur in austenite with 1·30, 1·07, and 0·37%Mn according to these investigations, A solubility curve at 0·09%Mn based on thermodynamic data[12] is also included.*

The Fe–O system was previously considered to be of a type similar to Fe–S as regards the solubilities in α- and γ-iron. Hence, the solubility has been reported to be 0·03% in α-iron immediately below the Ac_3 transformation point[13] and 0·002% in the γ-range independent of temperature.[14] These results have been questioned on thermodynamic grounds,[15] however, and recent investigations by Sifferlen[16, 17] indicate that the oxygen solubility tends to become zero with increasing purity and lattice perfection of the metal. The previous results then should have been due to oxygen bound to impurity atoms, e.g. silicon or manganese, and at grain boundaries and other

* In computing this solubility, equilibrium with pure MnS has been assumed. At low manganese contents this is not quite correct, however, as then the sulphide phase will contain some iron which decreases the activity {MnS}. Hence, the solubility would be somewhat lower than indicated in Fig. 1. On the other hand, the manganese content of the austenite is reduced as sulphide is precipitated.

TABLE I
Composition of steels, %

Steel	C	Mn	S	O	
K296	0·65	0·01	0·029	0·004	Vacuum-melted in a 15-kg induction furnace
K297	0·54	0·00[7]	0·034	0·005	
K300	0·59	0·00[4]	0·035	0·010	
K301	0·66	0·01[3]	0·075	0·009	
K314	0·75	0·01	0·076	0·005	
K311	0·84	0·09	0·057	0·002	
D43262	0·02	0·09	0·022	0·047	Ordinary rimmed steel
X321	0·01	0·08	0·030	0·132	Melted in a 50-kg induction furnace

lattice defects. Thus, the true oxygen solubility would be below the working range of ordinary methods of analysis.

Of the Fe–S–O system only the liquidus part has been investigated. According to Hilty and Crafts[18] this system has a ternary eutectic at 920° C and at 67%Fe, 24%S, and 9%O. These authors have also studied the effect of manganese on the Fe–S–O system.[19]

Keh and Van Vlack[3] made a careful study of the morphology of sulphides as a function of heat-treatment and of the modifications imposed by manganese and oxygen in this respect.

The object of the present investigation was to obtain more information on the influence of various factors on red-shortness, in particular the thermal history, in an attempt to establish the mechanism of embrittlement. It was considered important to distinguish between the effects of sulphur and oxygen more clearly than in previous investigations.

EXPERIMENTAL DETAILS

Most steels used in this investigation were vacuum-melted in a 15-kg induction furnace capable of a vacuum of about 2 mm Hg. The raw materials consisted of electrolytic iron, graphite, iron sulphide, and electrolytic manganese. The oxygen of the melts was largely removed by means of carbon additions and the carbon contents of the steels prepared in this way were consequently high. Two low-carbon steels were also investigated, one of which was an ordinary rimmed steel, and the other melted in a 50-kg induction furnace. The influence of oxygen on red-shortness was studied on bars forged from an electrolytic iron cathode with low sulphur content. All test materials were forged to bars 7 mm × 15 mm. Steels high in sulphur were forged either above or below the red-shortness range.

Results of chemical analysis of carbon, manganese, sulphur, and oxygen for the different melts are given in Table I. The amounts of other elements should be about the same as in the electrolytic iron used, namely

Si	Co	Zn	Mn, Cu, Cr, Al, As, P
0·003	0·005	0·002–0·040	< 0·001

The degree of red-shortness was determined by means of impact testing in a device shown in Fig. 2. The specimen was in the shape of a rectangular bar 7 mm × 15 mm × 65 mm with no notches. After

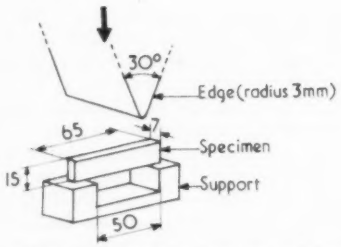


Fig. 2—Device for impact testing

heat-treatment it was rapidly taken out of the furnace and placed on its narrowest side on two supports 50 mm apart. An impact weight with an edge was then immediately released and hit the specimen in the middle of its length with an impact energy of 16 kg-m.* The weight came to a dead stop in a position corresponding to a bending angle of the specimen of about 70°. Immediately upon testing the specimen was usually quenched in brine and a section was prepared for metallographic inspection.

The degree of brittleness was judged from the appearance of the fracture according to a 6-graded scale shown in Fig. 3. The energy absorption was not measured. Prolonged heat-treatments were carried out in argon to prevent excessive oxidation or decarburization.

RESULTS

Effect of thermal history on red-shortness

In preliminary tests some steels proved to be completely ductile in impact testing whereas forging tests revealed pronounced brittleness. This discrepancy was found to be caused by differences in the heat-treatments employed in the respective methods. In

* The temperature decrease from taking out of the furnace to the instant of deformation was measured in a few single cases and amounted to about 5° C. The testing temperatures given have not been corrected for this decrease.

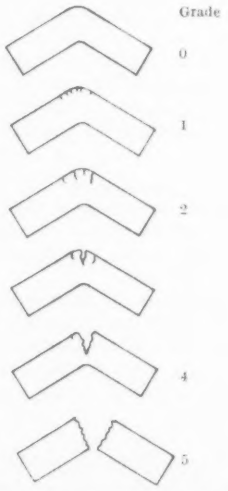


Fig. 3—Scale for judging red-shortness

TABLE II

T_{s5} as a function of cooling rate and testing temperature

Steel	S, %	T_t, °C	T_{s5}, °C		
			Cooling T_s–T_t*		
			A	*B*	*C*
K296	0·029	850	1 300	1 250	1 200
		900	1 300	1 250	1 150
		950	1 300	(1 150)	1 200
K297	0·034	850	1 300	1 100	1 100
		900	1 200	1 100	1 100
		950	1 150	1 100	1 100
K300	0·035	850	1 250	1 150	1 100
		900	1 200	1 100	1 050
		950	1 050	1 050	1 050
K301	0·075	850	1 200	1 050	1 050

* *A.* Rapid transfer of the specimen from a furnace at temperature T_s to a furnace at temperature T_t where the specimen was held for 4 min (length of time sufficient for equilibration of temperature) before testing
B. Cooling in air from T_s to T_t. Temperature decrease was followed with an optical pyrometer
C. Quenching from T_s in a lead pot at T_t where the specimen was held for 5 s (length of time sufficient for equilibration of temperature) before testing

impact testing the specimen was brought directly to the testing temperature (900–1 000° C) while in the forging test it was heated to a relatively high temperature (1 100–1 200° C) and then air-cooled to the testing temperature (1 000–900° C). As the different heat-treatments were likely to result in different states as regards sulphide precipitation a series of tests were carried out in which specimens were solution-treated at a high temperature T_s and then cooled at different rates to the testing temperature T_t (950–850° C). For each cooling rate and testing temperature different solution temperatures were tried. The tendency to red-shortness proved to increase as the solution temperature T_s was raised. To get a complete fracture in testing (grade 5 according to the scale) the solution

Fig. 4—Steel K300 (0·035%S). Heated to 1 250° C for 15 min, then transferred to a furnace at 850° C and held for 4 min before testing. Cracks along grain boundaries × 1 500

TABLE III

Red-shortness as a function of time at testing temperature, steel K296 (0·029%S) quenched from T_s in lead at 950° C

Time at 950° C	Red-shortness grade			
	1 300° C 15 min	1 200° C 30 min	1 150° C 45 min	1 100° C 1 h
5 s	5	5	4	3
1 min	3	...	2	3
4 ,,	3	3	2	2
10 ,,	3	...	...	...
30 ,,	3	2	1	1
1 h	2	...	...	...
2 ,,	1	...	...	...

temperature had to be raised above a certain minimum value T_{s5} which varied between 1 050° and 1 300° C according to cooling rate, testing temperature, and sulphur content. The higher T_{s5} is for a steel the larger should be the temperature range permissible for hot-working. Table II presents the T_{s5} values obtained at different cooling rates and testing temperatures for steels with different sulphur contents. The T_{s5} values are believed to be accurate within ± 25° C.

As is evident from Table II, T_{s5} decreases with increases in cooling rate, testing temperature T_t (950–850° C), and sulphur content.

By microscopic examination it was found that cracks usually followed austenite grain boundaries as shown in Fig. 4. Iron sulphide (troilite) was present as lenticularly shaped particles at the grain boundaries or as round droplets within the grains. The amount of sulphide increased with the sulphur content. Heat-treatment seemed to have no effect on the amount or the morphology of the sulphides. The austenitic grain size varied with T_s from ASTM 3 at 1 050° C to ASTM 1 above 1 100° C.*

Red-shortness when attaining equilibrium solubility at the testing temperature

The results cited, in particular the increased tendency to red-shortness with increased solution temperature, suggests that red-shortness is caused by sulphur in supersaturated solid solution in the austenite or possibly as a finely dispersed precipitate, as suggested by Hultgren and Herrlander.[11] Both of these distributions are likely to harden the γ-grains. In order to reduce the supersaturation and/or get larger and therefore less hardening sulphides, various test series were performed, involving isothermal precipitation of sulphide at temperature T_t as well as furnace-cooling from T_s to T_t.

Specimens of steel K296 with 0·029%S were heated to different solution temperatures T_s and held for a certain length of time; to account somewhat for the temperature dependence of the sulphur diffusivity, the lower the temperature, the longer was the time

* The reported grain sizes were determined according to the JKM scale and converted to the ASTM scale by the relation JKM + ASTM = 17

Fig. 5—Steel K297 (0·034%S). Furnace-cooled from 1 150° to 950° C, 8° C/h. Sulphide particles at grain boundary × 800

chosen. After this they were 'quenched' in a lead pot at 950° C and subjected to impact testing after various lengths of time at this temperature. The results are presented in Table III. There is a decrease in brittleness (after 5 s at 950° C) as T_s is lowered. There is also a definite return of ductility during the isothermal treatment at the testing temperature which was assumed to be due to the sulphur being transferred from solid solution, or from finely dispersed sulphide particles, into larger sulphide particles.

By microscopic examination it was found that the total amount of visible sulphide decreased as the solution temperature T_s was raised. Upon quenching from 1 300° C and holding for 5 s at 950° C, small sulphide inclusions that probably mainly represented sulphide melt undissolved at 1 300° C were still detected, however. After 2 h at 950° C the particles seemed to have increased somewhat in size and number. In the other instances the isothermal treatment seemed to have no influence in these respects.

Treatments similar to those presented in Table III were also performed on steels with higher sulphur contents (K300 and K301 with 0·035% and 0·075%S respectively). Although a slight decrease in the degree of red-shortness was noted, in a few cases isothermal treatment failed to restore the ductility for these steels. Slow cooling from T_s to T_t proved to be equally ineffective. In all instances the austenitic grain boundaries were found to be fairly well delineated by lenticular sulphides as in Fig. 5 and also as more or less continuous films (in K301 with 0·075%S).

It was thought that these grain-boundary precipitates were responsible for the residual red-shortness. Hence, by a heat-treatment precluding not only the supersaturation of the metal by sulphur but also the formation of grain-boundary precipitates it should be possible to remove red-shortness also in steels with high sulphur contents. With this line of thought the following experiments were made.

TABLE IV

Red-shortness as a function of time at testing temperature, steel K314 (0·076%S) brine-quenched from 1 300° C for 15 min

Time at 960° C	Red-shortness grade	
	A. Direct heating to to 960° C	*B*. Furnace cooling from 1 150° to 960° C
0	...	4
10 min	5	...
1 h	3	3·5
4 ,,	2	3·5
24 ,,	0	4
72 ,,	0	3·5
144 ,,	...	3·5

Specimens of steel K314 (0·076%S) were brine-quenched from 1 300° C and then divided into two series, *A* and *B*. The specimens of series *A* were heated to the testing temperature 960° C whereas those of series *B* were furnace-cooled from 1 150° C to the same testing temperature. In both series impact testing was performed after various lengths of time at the testing temperature. The results are given in Table IV. As is evident the brittleness is initially more pronounced in series *A* but has completely disappeared after one day at 960° C. In series *B* the brittleness remains about the same even after 6 days at 960° C. The following microscopic observations were made.

Series A—After 10 min at 960° C sulphide occurred as equiaxed rounded particles within the austenite grains and as more or less continuous films at austenite grain boundaries (Fig. 6). These films were thought to represent grain-boundary melt undissolved at the 1 300° C treatment. After 1 h at 960° C the films had partly transformed to rows of lenticularly shaped

Fig. 6—Steel K314 (0·076%S). Brine-quenched from 1 300° C, heated to 960° C for 10 min and quenched (series A). Sulphide at grain boundaries × 800

Fig. 7—Steel K314 (0·076%S). Brine-quenched from 1 300° C, heated to 950° C for 4 h and quenched (series A). Partly spheroidized sulphide at grain boundaries × 800

particles. This was still more marked after 4½ h, for which treatment the typical structure is shown in Fig. 7. In this case also a few tiny particles may be seen in the matrix. After 1 day at 960° C (Fig. 8), the grain-boundary sulphide films had spheroidized to an extent that grain-boundary networks were only vaguely indicated. A finely dispersed precipitate had formed in the matrix and was identified as iron sulphide by means of polarized light. On continued treatment the fine precipitate coalesced into coarser particles and it was no longer possible to observe any sulphide network. The austenitic grain size was about ASTM 7, seemingly independent of holding time at 960° C. Cracks usually followed the much coarser network initially marked by the undissolved sulphide

Fig. 8—Steel K314 (0·076%S). Brine-quenched from 1 300° C, heated to 960° C for 24 h and quenched (series A). Irregularly shaped sulphide particles at grain boundaries. Finely dispersed sulphide precipitate in the austenite matrix × 800

Fig. 9—Steel K314 (0·076%S). Brine-quenched from 1 300° C, furnace-cooled from 1 150° to 960° C, held at 960° C for 72 h and quenched (series B). Coarse sulphide particles at grain boundaries × 800

films which corresponded to the grain size of about ASTM 1 developed at 1 300° C. Obviously the latest stage of the return of ductility according to Table IV is linked to the disappearance of these sulphide films.

Series B—In all specimens coarse sulphide particles were present at austenite grain boundaries and seemed to be unaffected by prolonged holding at 960° C (*see* Fig. 9). No precipitate within the grains was visible. The austenitic grain size, here developed at 1 150° C, was about ASTM 3.

The results according to series *A* demonstrate that red-shortness can be removed by heat-treatment also at relatively high sulphur contents. The decrease in brittleness observed during the first 4 h (from grades 5 to 2) is probably largely due to sulphide precipitation or coalescence within the austenite grains since the sulphide films still remain fairly unchanged. The complete removal of red-shortness, however, is only achieved at a later stage when the films have disappeared. In series *B* spheroidization is hardly noticeable because the sulphides here are much coarser and almost entirely located at grain boundaries, which is believed to cause the brittleness in this case.

Effect of manganese on red-shortness induced by sulphur

To find out how red-shortness responded to heat-treatments in the presence of manganese, two steels with 0·09%Mn were investigated. One of these, D43262, was an ordinary rimmed low-carbon steel with 0·022%S, the other, K311, was vacuum-melted with a high carbon content like the steels previously described and contained 0·057%S (cf. Table I).

Steel D43262 was subjected to similar cooling treatments as those recorded in Table II. Also in this case there existed a minimum solution temperature T_{85} from which the specimen had to cool in order to display complete fracture (grade 5) at the testing

TABLE V

Red-shortness as a function of time at testing temperature, steel K311 (0·057%S–0·09%Mn) quenched from T_s in lead at 950° C

Time at 950° C	Red-shortness grade	
	1 300° C, 15 min	1 200° C, 15 min
5 s	5	1·5
15 ,,	5	1
1 min	5	1
4 ,,	5	1
10 ,,	5	...
30 ,,	5	...
1 h	4	...
2 ,,	3	...

TABLE VI

Red-shortness as a function of time at testing temperature, steel K311 (0·057%S–0·09%Mn) brine-quenched from 1 300° C for 15 min

Time at 960° C	Red-shortness grade	
	A. Direct heating to 960° C	*B*. Furnace cooling from 1 150° to 960° C
0	...	0
3 min	5	...
6 ,,	4	...
10 ,,	1·5	...
1 h	1	...
5 ,,	0	...
24 ,,	...	0

temperature T_t. At $T_t = 950°$ C and for different cooling rates the following T_{85} values were obtained:

Transfer to a box furnace (cooling rate *A*, Table II)	$T_{85} = 1\,250°$ C
Air cooling (cooling rate *B*, Table II)	$T_{85} = 1\,200°$ C
Lead quenching (cooling rate *C*, Table II)	$T_{85} = 1\,150°$ C

Also here T_{85} decreased with increasing rate of cooling. Comparison with the results of Table I indicates, however, that the manganese does not affect the red-shortness very much in the present case. Presumably, because of the high oxygen content (0·047%O) much of the manganese is tied up in (Fe,Mn)O slag inclusions.

With steel K311, the effect of isothermal treatment at the testing temperature was studied. Specimens were solution-treated at 1 300° and 1 200° C respectively and quenched in lead at $T_t = 950°$ C. The results are given in Table V. Quenching from 1 300° C resulted in complete fracture at 950° C for holding periods at the latter temperature shorter than 30 min. The brittleness then clearly decreased with time although periods longer than 2 h were not investigated. After quenching from 1 200° C the initial brittleness was only slight but also in this case a definite decrease during the isothermal treatment was obvious.

Under the microscope all specimens displayed rounded particles of MnS or duplex MnS–FeS. Their shapes and distribution appeared to be unaffected by heat-treatment. The austenite grain size was about ASTM 1 in all instances.

Test series like those recorded for K314 in Table IV, series *A* and *B*, were also carried out with K311 as shown in Table VI. Upon quenching from 1 300° C to room temperature and direct reheating to 960° C (series *A*) red-shortness was fully developed after holding for a few minutes. However, it decreased rapidly and had disappeared completely after 5 h. After furnace-cooling from 1 150° to 960° C (series *B*) the steel was fully ductile.

Under the microscope, the appearance of the sulphide particles in these specimens did not differ noticeably from that reported for the specimens treated according to Table V. In particular, there was no excessive formation of grain-boundary sulphides upon furnace-cooling (series *B*) as was found for the manganese-free steel K314 in the corresponding treatment (cf. Fig. 9). The austenite grain size was ASTM 6 for series *A* and ASTM 3·5 for series *B*.

Tendency to brittleness below Ac_3

To compare the tendency to red-shortness above and below the temperature of the $\gamma \rightarrow \alpha$ transformation, impact tests were carried out on steel X321 with 0·030%S after heating for 5 min at different temperatures above and below Ac_3. The results shown in Fig. 10 indicated that red-shortness was almost entirely restricted to the γ-range.

Embrittlement by oxygen

To find out whether oxygen alone will cause red-shortness, test material was forged from an electrolytic iron cathode with 0·004%S and subjected to

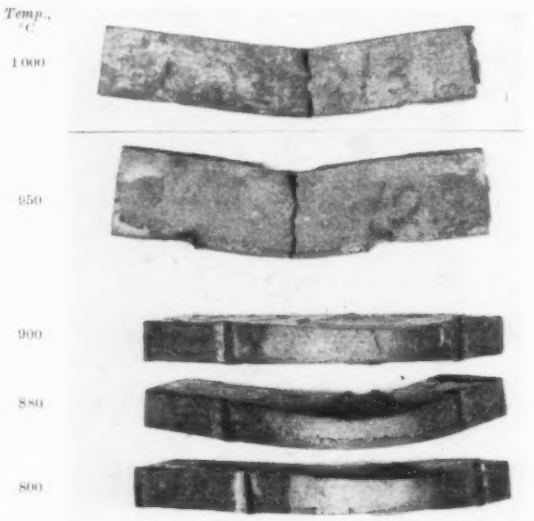


Fig. 10—Fracture appearance of steel X321 (0·030%S) upon impact-testing at temperatures above and below Ac_3

TABLE VII

Red-shortness in iron containing oxygen
(Test material forged from electrolytic iron cathodes low in sulphur and manganese)

Mark	X1	X2	Y1	Y2
Pre-treatment	Forged at 1 100° C	As X1 then oxidizing anneal at 1 300° C[1]	As X1 then deoxidized at 1 200° C for 3 weeks in pure hydrogen	As Y1 then oxidizing anneal at 1 300° C[1]
% O[2]	0·027–0·032	0·028	0·0009	0·035
% S	0·004	...	0·004	...
Treatment before impact testing	Red-shortness grade			
870° C, 10 min	0		0	
900° C, „ „	5		0	
950° C, „ „	5	1	0	0
1 000° C, „ „	1		0	
1 050° C, „ „	0		0	
1 250° C, 15 min quenched to 950° C, 1 min	3[3]		0	0
1 250° C, 15 min quenched to 950° C, 10 min	1[3]		0	0
1 300° C, 10 min transferred to furnace at 950° C, 4 min	3	0		
1 300° C, 10 min transferred to furnace at 950° C, 1 h	5	1		

1. Annealing for 18 h in argon containing some moisture 2. Vacuum extraction 3. Solution treatment at 1 300° C instead of 1 250° C

impact testing after various pretreatments. Data for these treatments as well as testing results are presented in Table VII.

Preliminary tests in the as-forged condition (iron X1, 0·027–0·032%O) were carried out upon cooling at various rates from different temperatures T_s to the testing temperature T_t where the specimens were isothermally treated for various lengths of time. In these experiments, not reported in Table VII, the degree of brittleness varied without consistent trends. Under the microscope the specimens displayed slag inclusions as rounded particles or films, the latter sometimes forming more or less continuous networks. The films probably consisted of oxide and possibly sulphide and were believed to originate from entrapped electrolyte or oxidized pores in the cathode material. By a homogenization treatment at 1 300° C for 18 h during which the oxygen content remained substantially unchanged (iron X2, 0·028%O) the films and also the red-shortness disappeared almost completely (cf. Table VII). Hence, it was supposed that the brittleness encountered in iron X1 was brought about by the films.

The deoxidized iron Y1 with 0·0009%O contained but a few non-metallic inclusions and proved to be ductile upon all treatments employed. Oxygen was then introduced by an oxidizing anneal at 1 300° C after which the material, now called Y2, contained 0·035%O. This material did not exhibit brittleness after any of the treatments given. In the microstructure plenty of rounded and evenly distributed slag inclusions were present.

Since the oxygen contents of irons X2 and Y2 probably exceed the oxygen solubility in austenite by a factor of 10 or more[14, 16, 17] it may be concluded that oxygen does not cause red-shortness at low sulphur contents, even in the absence of manganese. The brittleness observed with iron X1 is to be regarded as an abnormal phenomenon conditioned by the unusual method of preparation.

DISCUSSION

Deformation and fracture

Deformation of metals occurs by means of regular slip (including twinning) and, at high temperatures (closer to the melting point), also by viscous flow at grain boundaries. The latter mechanism implies atomic diffusion and is favoured by low deformation rates. When viscous flow occurs shear stresses at grain boundaries are relaxed and, as the flow proceeds, stress concentrations are created at certain 'locked' points at the boundaries, e.g. at edges or corners. The stress concentrations may initiate cracks that spread along the grain boundaries. This type of intercrystalline failure is common in metals at high temperatures[20] and is likely to be favoured by a rise in the resistance to regular slip within the grains as well as by a decrease in the shear strength of grain boundaries.

According to the interpretation of the present results previously indicated, both these effects are represented in the two different phenomena that singly or combined lead to red-shortness, namely:

(i) Sulphur in solid solution or as finely dispersed precipitate in the austenite (likely to increase the resistance to regular slip)
(ii) Sulphide precipitates at austenite grain boundaries (reduce the intergranular shear strength).

As has been shown, both phenomena may be eliminated and the ductility restored by heat-treatment.

It might be argued that the deformation rate in the present testing method is too high to allow significant grain-boundary flow. However, even a minute amount of such a flow is likely to cause stress concentrations capable of starting cracks.

Hardening effect of sulphur

Sulphur, dissolved or as finely dispersed sulphide, is likely to increase the hardness of the austenite. It is not possible to tell which of these hardening effects is the pertinent one; they may both be effective in successive stages. The sulphur might also accomplish its hardening effect when existing in an intermediate stage. The fact that red-shortness is fully developed immediately upon quenching from a high temperature to the testing temperature (cf. Tables III–VI) favours the idea of solid-solution hardening.

A rise in solution temperature would increase the amount of dissolved sulphur (*see* Fig. 1) and hence upon quenching to the testing temperature the hardness, i.e. the brittleness of the austenite, would also increase (e.g. *see* Table III). For a given degree of brittleness, e.g. grade 5, a minimum solution temperature should then be required.

The observation that the solution temperature required for red-shortness in grade 5, i.e. T_{s5}, is increased at slower cooling, as reported in Table II, may result from sulphide precipitation during cooling or coalescence of finely dispersed precipitate. The increase in T_{s5} at lowered testing temperature T_t could be accounted for by a decrease in the supposed grain-boundary viscosity at lower T_t, which must be compensated for by more sulphur in solid solution.

Effect of grain-boundary sulphides

At sulphur contents above 0·030%, slow cooling through the γ-range results in a preferred precipitation of iron sulphide at the grain boundaries. Due to the low surface energy of liquid/γ and FeS/γ interfaces, as compared to the surface energy of a γ/γ grain boundary the precipitates will spread as more or less continuous films round the γ-grains.[3] Obviously, above the eutectic temperature (988° C) these films cannot support a shear stress; it is also reasonable to assume that, at temperatures somewhat below the eutectic, the shear strength of the sulphide itself or of the FeS/γ interface is considerably lower than the shear strength of a pure austenite grain boundary.[9]

According to Keh and Van Vlack[3] the dihedral angle of sulphide melt (above 988° C) or FeS in a γ/γ boundary decreases as the temperature increases. At 1 050° C the angle is about 30° whereas at 1 300° C it is 0° implying a tendency of the melt to envelop the austenite grains. Hence, a film formed at a high temperature will, upon a subsequent treatment at a lower temperature, break up into a row of lenticular particles.

Figures 6–8 illustrate this effect obtained by isothermal treatment at 960° C upon a preceding quench from 1 300° C for steel K314 (cf. Table IV, series *A*).* This treatment has completely restored the ductility in spite of the high sulphur content (0·076%S) because:

(i) Sulphur has been precipitated from the solid solution in particles large enough to reduce the hardness of the austenite to a harmless level
(ii) Embrittling grain-boundary sulphides have been spheroidized.

* In this case some portions of the films are no longer located at grain boundaries owing to the $\gamma \rightarrow \alpha \rightarrow \gamma$ transformation. Spheroidization might then occur in these places regardless of a change in interfacial energy.

On the other hand, red-shortness in steel K314 is not removed when the isothermal treatment at 960° C is preceded by furnace cooling from 1 150° C (cf. Table IV, series *B*). In this case sulphide melt has precipitated at grain boundaries during the furnace cooling and subsequently transformed to coarse sulphide particles (Fig. 9). Prolonged treatment at 960° C has not been effective in reducing the grain-boundary area occupied by sulphides and hence the red-shortness remains.

Apart from visible particles, submicroscopic films or some other kind of sulphur enrichment at grain boundaries have been suggested as causes of red-shortness. According to the autoradiographic studies by Keh and Van Vlack,[3] however, such a distribution of sulphur is not likely.

Effect of manganese

Manganese seems to counteract red-shortness in two ways:

(i) By lowering the solubility of sulphur in austenite[1,2] (cf. Fig. 1) which reduces the possibility of hardening
(ii) By increasing the interfacial energy between sulphide and austenite[3] so that discrete particles rather than continuous grain-boundary films are formed.

Thus both the embrittling mechanisms that are attributed to sulphur are neutralized. The effect of manganese in lowering the sulphur solubility may be compensated for by raising the solution temperature (cf. Fig. 1). Accordingly steel K311 with 0·057%S and 0·09%Mn was fully red-short upon quenching from 1 300° C whereas quenching from 1 200° C resulted in only slight brittleness (cf. Table V). The corresponding sulphur solubilities may be estimated from Fig. 1 to about 0·02 and 0·01%, respectively. The effect of manganese in increasing the sulphide/γ interfacial energy is clearly demonstrated by the fact that grain-boundary films were not observed in K311 even after furnace cooling. Thus the film mechanism may be excluded as a cause for the red-shortness in this material. According to the formula of Anderson *et al.*[6] the manganese content necessary to prevent red-shortness at 0·057%S is 0·10% as compared to 0·09% in steel K311.

Brittleness below Ar_3

The main reason for the restriction of red-shortness to the γ-range is probably the greater resistance to deformation in austenite as compared to that in ferrite. The fact that FeS has a greater dihedral angle in a ferrite than in an austenite grain boundary[3] also disfavours brittleness in the α-range. However, brittleness in the α-range at quite low sulphur contents has been reported by Hultgren and Herrlander.[11]

Effect of carbon on the sulphur solubility in austenite

Most of the test materials used had rather high carbon contents. Carbon was used for deoxidation because it leaves no deoxidation product in the steel and admits a simple melting procedure. Carbon *per se* has probably no influence on red-shortness. Apart from extending the austenite range to lower temperatures it may also lower the sulphur solubility in austenite, however, and in both these ways it exerts an indirect effect on red-shortness. There is no

information regarding the influence of carbon on the solubility of sulphur in austenite but Morris and Buehl[21] found that carbon increased the activity of sulphur in liquid iron at 1 600° C. Thus at 0·5% and 1%C the activity coefficients of sulphur were about 1·2 and 1·4, respectively. The temperature dependence was very slight. Assuming an effect of the same magnitude in austenite would imply a decrease in sulphur solubility to between 80 and 70% of the values in the Fe–S diagram (Fig. 1) at carbon contents ranging from 0·5% to 0·8%. Some evidence supporting this assumption was obtained by microscopic investigation of specimens with 0·040%S and 0·55%C that had been quenched from various temperatures between 1 200° and 1 350° C. The amount of sulphide markedly decreased with raising quenching temperature. At 1 350° C the sulphide was almost absent implying that the sulphur solubility is slightly below 0·040% at this temperature. According to Fig. 1 the corresponding solubility in the pure Fe–S system is 0·048%. Hence the activity coefficient for sulphur in austenite at 1 350° C is about 1·2 at 0·55%C in qualitative agreement with the findings for liquid iron.* In the absence of exact data the influence of carbon has not been accounted for in the references made to Fig. 1.

Effect of oxygen

Since the oxygen solubility in γ-iron even at high temperatures appears to be very small, oxygen cannot be expected to harden the austenite or to precipitate as oxide at grain boundaries. Hence, there seems to be no basis for assuming oxygen to cause red-shortness as is also confirmed by the present experiments. In view of the reported low oxygen solubility it may seem noteworthy that a comparatively high and uniformly distributed oxygen content could be introduced into iron Y2 by an oxidation anneal at 1 300° C (cf. Table VII). However, this could be attributed to internal oxidation mainly of silicon which according to chemical analysis amounted to 0·005% in iron Y2.†

It was shown by Keh and Van Vlack[3] that the dihedral angle of intergranular sulphide inclusions was increased by oxygen at least at high temperatures. This would imply that oxygen tends to counteract the embrittling effects of grain-boundary sulphides. Oxygen possibly also lowers the sulphur solubility in austenite as it might be expected to dissolve to some extent in the sulphide thus lowering the sulphur activity of this phase. On the other hand, in the presence of manganese, oxygen should promote red-shortness since it lowers the effective manganese content in the austenite by forming (Fe,Mn)O slag inclusions. This is probably the case in steel D43262. Work on the combined effect of sulphur and oxygen on red-shortness is continuing in the authors' laboratory.

Effect of grain size

The austenitic grain size might be thought to affect red-shortness. In particular one would expect a more pronounced brittleness at a large grain size. However, there is no evidence for such an effect as fine-grained steels were also found to be fully red-short (cf. Table IV, series *A* and Table V, series *A*).

CONCLUSIONS

(1) Sulphur induces red-shortness in steel by two different mechanisms:

(*a*) Sulphur in supersaturated solid solution or as finely dispersed sulphide precipitate hardens the austenite. The deformation then occurs mainly by shear along grain boundaries causing stress concentrations which initiate inter-granular fracture.

(*b*) Sulphur in the form of elongated sulphide precipitates or films at austenite grain boundaries promotes grain-boundary shear and thus intergranular fracture.

(2) By suitable heat-treatment one or both of these mechanisms may be eliminated.

(3) Red-shortness appears to be restricted to the γ-range.

(4) Manganese counteracts red-shortness by:

(*a*) Lowering the sulphur solubility in austenite thus decreasing the potentiality for hardening.

(*b*) Forming manganese sulphide which does not form embrittling films at grain boundaries.

(5) Oxygen does not cause red-shortness in manganese-free iron at a low sulphur content (0·004%S).

Acknowledgments

Thanks are due to the Stora Kopparbergs Bergslags Aktiebolag for permission to publish this paper, and to Professor Bo Kalling, Head of the Research Department, who initiated this work and has followed it with keen interest.

References

1. T. Rosenqvist and B. L. Dunicz: *Trans AIME*, 1952, vol. 194, pp. 604–608.
2. R. Vogel and W. Hotop: *Arch. Eisenhütt.*, 1937/38, vol. 11, p. 41.
3. A. S. Keh and L. H. Van Vlack: *Trans AIME*, 1956, vol. 206, pp. 950–958.
4. A. McCance: Symposium on Steel Making, *ISI Spec. Rep.* No. 22, 1938, pp. 364–371.
5. C. T. Anderson, R. W. Kimball, and F. R. Cattoir: *Trans AIME*, 1953, vol. 197, pp. 525–529.
6. C. T. Anderson *et al.*: *Ibid.*, 1954, vol. 200, pp. 835–837.
7. B. Kalling: Unpublished work.
8. E. W. Fell: *Arch. Eisenhütt.*, 1930/31, vol. 4, pp. 393–400.
9. R. Kenyon: *Trans ASST*, 1928, vol. 13, pp. 457–473.
10. J. Görrissen: *Tidsskr. Kjemi Bergv. Met.*, 1949, vol. 5, pp. 83–89.
11. A. Hultgren and B. Herrlander: *Trans AIME*, 1947, vol. 172, pp. 493–509.
12. E. T. Turkdogan, S. Ignatowicz, and J. Pearson: *JISI*, 1955, vol. 180, pp. 349–354.
13. A. U. Seybolt: *Trans AIME*, 1954, vol. 200, pp. 641–644.

* Darken[22] has proposed a model according to which each carbon atom in the melt is surrounded by 6 iron atoms none of which could be substituted by a sulphur atom. Each atomic-% of carbon would then lower the equilibrium content of sulphur by 6%, i.e. increase the activity coefficient for sulphur by 6% in accordance with the findings of Morris and Buehl.[21] The model may apply to austenite, as here, too, each carbon atom is surrounded by 6 iron atoms.

† Electrolytical separation of slag inclusions from the specimens gave a residue of black globules, which on analysis were found to contain about 5% SiO_2.

References (continued)

14. J. A. KITCHENER *et al.*: *Acta Met.*, 1953, vol. 1, pp. 93–101.
15. J. L. MEIJERING: *Ibid.*, 1955, vol. 3, pp. 157–162.
16. R. SIFFERLEN: *Compt. Rend.*, 1955, vol. 240, pp. 2526–2528.
17. R. SIFFERLEN: *Ibid.*, 1957, vol. 244, pp. 1192–1193.
18. D. C. HILTY and W. CRAFTS: *Trans AIME*, 1952, vol. 194, pp. 1307–1312.
19. D. C. HILTY and W. CRAFTS: *Ibid.*, 1954, vol. 200, pp. 959–967.
20. N. J. PETCH: "Progress in Metal Physics," vol. 5, pp. 1–52: 1954, London, Pergamon Press.
    C. W. CHEN and E. S. MACHLIN: *Trans AIME*, 1957, vol. 209, pp. 829–835.
21. J. P. MORRIS and R. C. BUEHL: *Ibid.*, 1950, vol. 188, pp. 317–322.
22. L. S. DARKEN: *Ibid.*, 1950, vol. 188, p. 1349.
23. Å. JOSEFSSON: *Jernkont Ann.*, 1955, vol. 139, pp. 225–249.

Longitudinal panel cracking in ingots

By S. C. Desai, B.Sc., (Met. Eng.)

INTRODUCTION

LONGITUDINAL PANEL CRACKS are, as the term suggests, a particular type of ingot crack appearing in a longitudinal direction on the face of an ingot. Figure 1 illustrates a typical example. Generally, panel cracks occur near the centre of the face and extend in depth up to or beyond the mid-radial position. They may occur on one, two or, very occasionally, three faces of the ingot and may extend over almost the entire length, in which case the whole of the ingot has to be scrapped. There are recorded instances where panel cracks have led to 60–70% of the ingots in a cast being scrapped, which obviously constitutes a most serious loss.

Paper SM/BF/170/58 of the Forging Ingots Subcommittee of the Steelmaking Division of the British Iron and Steel Research Association, received on 23rd January, 1959. The views expressed are the author's, and are not necessarily endorsed by the Committee as a body.

The author is with the BISRA Sheffield laboratories.

SYNOPSIS

The examination of available data on the occurrence of longitudinal panel cracks shows that they are largely confined to steels of a composition range such that the pearlite grains are enveloped in a more or less continuous thin boundary of ferrite. Within this range, the susceptibility of any particular steel to panel cracking is greatly influenced by its aluminium and nitrogen contents.

Metallurgical examination has established the intergranular nature of the crack and the probability of it occurring at temperatures below about 850° C. Hot tensile tests on as-cast samples of susceptible steels indicate their low ductility at temperatures in the region of 600° C and show that the ductility is reduced by increases in the aluminium content and, to a lesser degree, the nitrogen content. Partial replacement of the aluminium by titanium and vanadium improves the ductility at these temperatures, but zirconium appears to have no effect. Possible means of minimizing the incidence of panel cracking are suggested. 1673

OCCURRENCE OF PANEL CRACKING

Panel cracking is mostly encountered in steels treated with aluminium to produce inherent fine grain size. Data available to the Forging Ingots Subcommittee have shown that this defect is generally confined to steels within a limited range of carbon

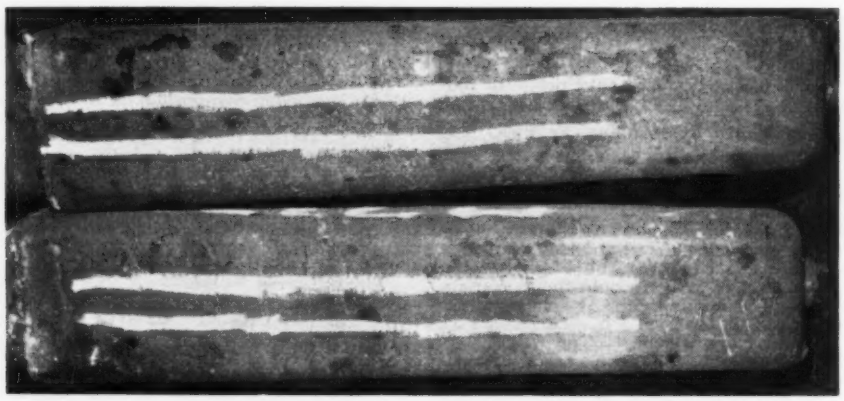


Fig. 1—Longitudinal panel cracks in 11½-in. square basic electric ingots of En 18 steel, grain-controlled with Al

TABLE I

Effect of aluminium additions

Al, oz/ton of steel	Cracked ingots, %
7	3·0
13	6·7
16	12·3
24	17·4

contents, about 0·4–0·7%C in plain carbon steels, and somewhat lower in Ni, Ni–Cr, and 1–1½%Mn steels.

The steelmaking process has an important bearing on the susceptibility of the steel to panel cracking, the different processes in order of their decreasing susceptibilities being: electric arc, basic open-hearth, and acid open-hearth. The defect is very seldom encountered in steels made by the acid OH process.

Larger ingots are more prone to cracking than those of smaller size. It has been noticed that small ingots (below about 9 in. square) are practically immune to panel cracking but as the size increases they become progressively worse in their susceptibilities to this trouble. If the ingots are stripped as hot as possible and then cooled very slowly or hot charged for rolling, the occurrence of panel cracking is greatly reduced.

It has been suggested[1] that casting conditions can contribute towards the incidence of panel cracking and in particular that teeming temperature and teeming rate should be carefully regulated. Care should also be taken in spacing the moulds in the casting pit, and the metal should be teemed centrally to avoid non-uniform chilling of the ingot.

Effects of aluminium and nitrogen

Longitudinal panel cracking is closely related to the aluminium and nitrogen contents of the steel. A statistical study made at one works[2] on a large batch of 21½-in. round ingots has shown that the incidence of panel cracking is increased with increasing amounts of aluminium addition (*see* Table I).

This is further confirmed by results obtained at another works[3] where a comparative study was made on basic OH and electric arc furnace steels. The results are given in Tables II and III. The average nitrogen contents for basic OH and basic electric steels are given as 0·005 and 0·009% respectively,

TABLE II

Relation between total aluminium content and percentage cracking in basic OH and basic electric furnace processes

Total Al, %	Cracking, %	
	Basic OH	Basic electric
< 0·015	nil	nil
0·016–0·019	1·2	23
0·020–0·023	4·6	52
0·024–0·031	36	...

TABLE III

Total Al and N contents in relation to panel cracking of ingots

	Ingots showing longitudinal cracks, %	
	0·016–0·020%Al	0·021–0·023%Al
0·005–0·006%N	7	19
0·007–0·009%N	28	37
0·010–0·012%N	39	53

and the close correlation between aluminium and nitrogen contents and ingot cracking is emphasized by the data in these two tables.

Characteristics and probable mechanism of panel cracking

The Sub-committee's first approach to the problem of panel cracking consisted of careful examination of cracked and uncracked ingots from the same cast, in an attempt to determine any significant difference between them.

Transverse ingot sections (*see* Figs. 2 and 3) submitted by members of the Sub-committee were sulphur-printed and macro-etched, but neither technique revealed any abnormalities which could be associated with the crack. Chemical analysis showed no significant differences between cracked and uncracked ingots, nor between the cracked and uncracked faces of the same ingot. Similarly, inclusion counts[3] based on the Fox chart showed no appreciable differences.

Specimens taken for microscopic examination from various parts of the cracked ingots revealed a thin grain boundary of ferrite enveloping pearlite grains. Continuous grain boundaries of ferrite were occasionally present even in the centre of the ingot where the prior grain size was larger.

It was difficult to examine the nature of the crack

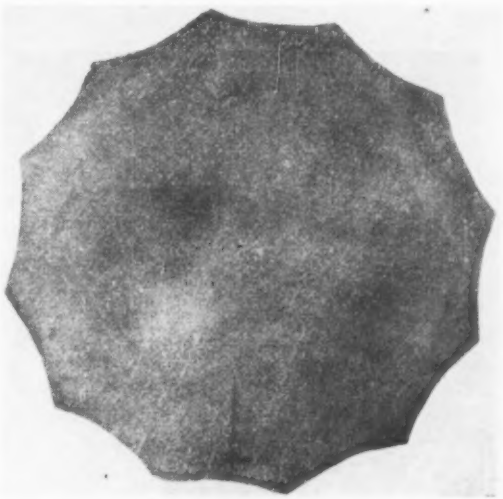


Fig. 2—Etched transverse section of a 0·6%C 15-in. duodecagonal basic OH ingot showing panel crack

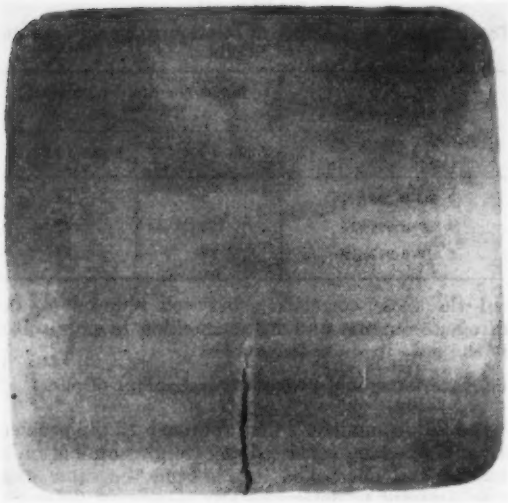


Fig. 3—Etched transverse section of a 0·55%C 14½-in. square ingot showing panel crack

near the face of the ingot because of its width, but following it progressively as it extended into the ingot and became narrower, it was quite evident that the crack was mostly intergranular (Fig. 4) following the ferrite network around the pearlite grains. Ferrite was very often observed only on one side of the crack, as shown in Fig. 5. Oxidation of the crack was only superficial and there was no decarburization present around it.

Manganese sulphide inclusions were present in the grain-boundary ferrite (Fig. 6) and were also sometimes found within the pearlite with ferrite pools nucleated on them (Fig. 7). Aluminous types of inclusions, occurring in stringers, were found only occasionally in the ferrite network (Figs. 8*a* and *b*).

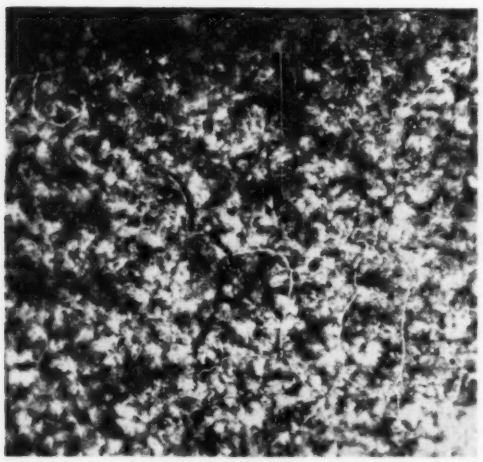


Fig. 4—Intergranular crack following the ferrite network × 10

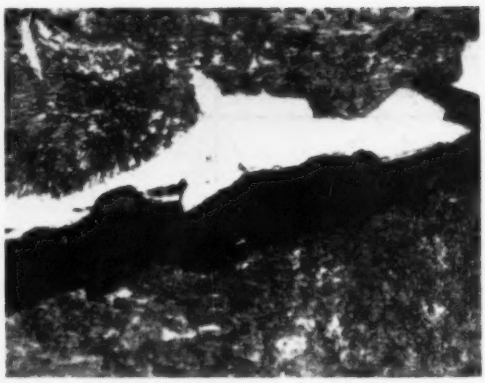


Fig. 5—Crack along pearlite ferrite interface × 750

It was not possible to associate these in any way with the panel cracking.

It is very significant that the longitudinal cracks always occur near the centre of the panel. Though not yet certain, it is generally agreed that panel cracks originate internally and propagate to the surface. In discussing the probable mechanism of crack formation, Bacon[3] suggested that "as a square ingot solidifies the corners freeze more rapidly than the faces, and on final solidification the ingot is much hotter in some places than in others. The outer part of the ingot is comparatively rigid whilst the centre, just after solidification, is at a temperature around 1 500° C. As it cools down further, the centre is seeking to contract within a rigid framework. High tensile stresses are set up and finally, owing to these stresses, there is a pull at the weakest point which is a position about a quarter of the way towards the centre, at half the ingot width. This point would at any given time be hotter than any other point along the line a–b, and also subject to the highest tensile stress." The diagrammatic sketch (Fig. 9) indicates the progress of solidification with the corner effect exaggerated.

Longitudinal panel cracking mostly occurs in steels within a limited range of carbon contents, about 0·4–

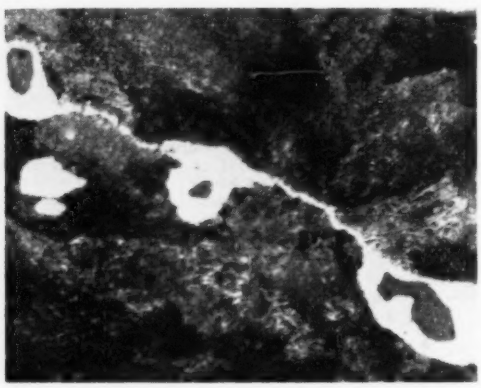


Fig. 6—MnS inclusion in grain-boundary ferrite × 500

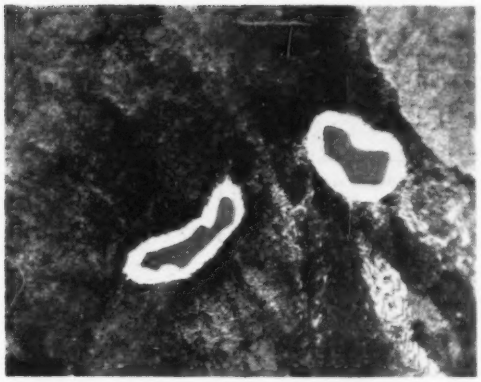


Fig. 7—Ferrite pools nucleated by MnS inclusions × 500

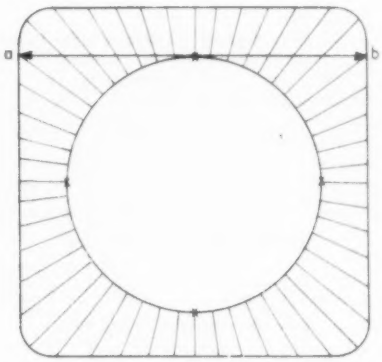


Fig. 9—Progress of solidification of ingot, corner effect exaggerated

0·7%C. In low-alloy steels, the carbon content is on the lower side of the range. This range of carbon contents is such that the steel contains pearlite enveloped by a thin grain boundary of ferrite, the addition of alloying elements reducing the amount of carbon necessary for formation of the eutectoid. This thin continuous grain boundary of ferrite is less capable of withstanding the high tensile stresses developed in the ingot while cooling, and the presence of any fine precipitate or film may weaken it further, thus contributing in making these steels more susceptible to panel cracking.

Microexamination has revealed only superficial oxidation of the crack and the absence of any decarburization around it. It has also shown that it very often runs along the pearlite/ferrite interface, suggesting that the cracking occurs at a lower temperature, probably below 850° C, when the ferrite network is in existence. This is further supported by the observed reduction in the incidence of panel cracking when ingots are stripped hot and then slowly cooled or hot charged for rolling.

The precipitation of aluminium nitride in steel castings is known to cause intergranular fractures. The intergranular nature of panel cracking and its increased incidence with increasing amounts of aluminium and nitrogen suggest that aluminium nitride also plays an important part in the formation of this particular ingot defect.

Following this preliminary examination, the Subcommittee's next approach to the problem of longitudinal panel cracking was of a more fundamental nature. Experimental work carried out at the BISRA laboratories will now be described.

EXPERIMENTAL WORK

From the collected data on longitudinal panel cracking it is clearly evident that aluminium, nitrogen, and grain boundary ferrite all play an important part. It is established that the crack is intergranular and occurs at relatively low temperatures, below about 850° C. It was felt that a knowledge of the tensile properties of steels at temperatures up to this level would lead to a clearer understanding of the causes of panel cracking and accordingly several series of hot tensile tests on various steels in the as-cast condition were carried out. To complete the picture, room-temperature tests were also included in each case.

The first series of hot tensile tests was made on 0·6%C steel, prepared with varying aluminium and nitrogen contents in small high-frequency furnace heats. The results of the tests are given in Table IV, and together with the curves in Figs. 10 and 11 they show that there is very little difference in the tensile

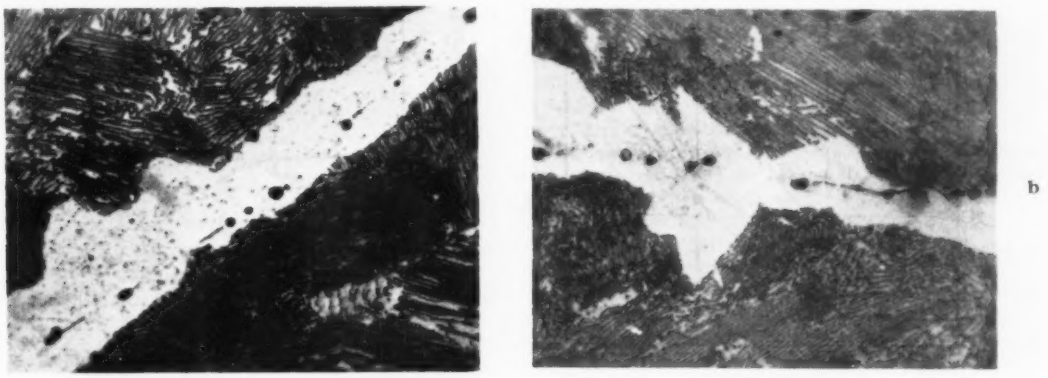


Fig. 8—(*a*) and (*b*): Aluminous inclusions in grain-boundary ferrite × 1 000

TABLE IV
Results of hot tensile tests on steels with varying Al and N contents

No.	Composition, %				Grain size ASTM No.	Temperature, °C	Tensile properties		
	C	Si	Mn	Other elements			UTS	Elongation, %	RA, %
1	0·63	0·26	0·84	0·008 N 0·01 Al 0·0025 Al (sol) 0·0033 N as AlN (Low nitrogen—low aluminium)	4	Room temp. 500 600 700 800	45·6 22·5 11·8 6·1 3·2	9 12·5 15 25 69	8 25 24 14 72
2	0·64	0·26	0·84	0·008 N 0·07 Al 0·046 Al (sol) 0·0065 N as AlN (Low nitrogen—high aluminium)	6–7	Room temp. 500 600 700 800	45 19·8 11·1 6·7 3·4	11 10 7·5 22·5 50	9·2 14 8 6 32
3	0·645	0·26	0·79	0·015 N 0·01 Al 0·002 Al (sol) 0·0024 N as AlN (High nitrogen—low aluminium)	4–5	Room temp. 500 600 700 800	44·9 23·9 11·8 4·9 3·0	10 16 17·5 44 69	8·5 18 22 45 76
4	0·635	0·23	0·75	0·021 N 0·065 Al 0·040 Al (sol) 0·0108 N as AlN (High nitrogen—high aluminium)	7–8	Room temp. 500 600 700 800	46·2 20·2 11·9 6·1 3·8	12·5 7·5 4 6·3 21	19 6 6 6 15

Note: Tests were carried out on specimens machined out of 4-in. square ingots, from a high-frequency furnace, in as-cast condition. It was not possible to test them in duplicate because no more material was available

properties at room temperature or in tensile strength at elevated temperatures, but the steels containing low-nitrogen–high-aluminium and high-nitrogen–high-aluminium give lower figures for elongation and reduction in area at high temperatures. Nitrogen does not appear to have any appreciable effect unless accompanied by a high aluminium content; on the other hand, a high aluminium content has a definite effect even when the nitrogen content is low, the effect being even more pronounced when the nitrogen is also high.

These results show that aluminium additions can cause a distinct reduction in the ductility of the steel at temperatures at which panel cracking is liable to occur. To investigate this effect more closely, a further series of tests was carried out on five ingots of En 18 steel, produced in the BISRA experimental arc furnace with ladle aluminium additions of 0, 6, 12, 18, and 24 oz/ton, respectively. The results of these tests are given in Table V.

From the results it can be seen that increasing the aluminium addition has the effect of reducing the ductility of En 18 steel, which is very susceptible to panel cracking. It is also very significant that the ductility is at its lowest around 600° C which suggests that cracks might be developing in that temperature region. Steel no. 3 was inadvertently low in carbon and the tests show that it was considerably more

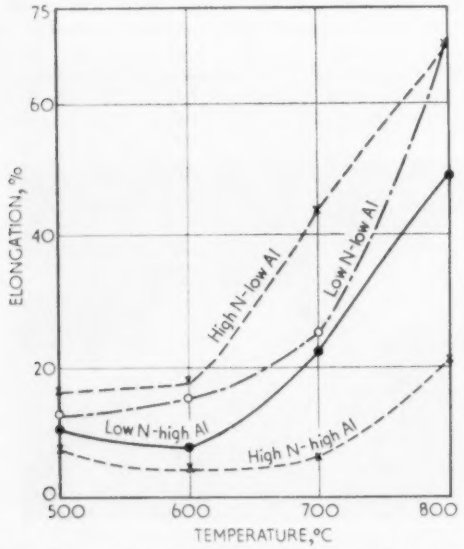


Fig. 10—Temperature *v.* elongation, steels as indicated

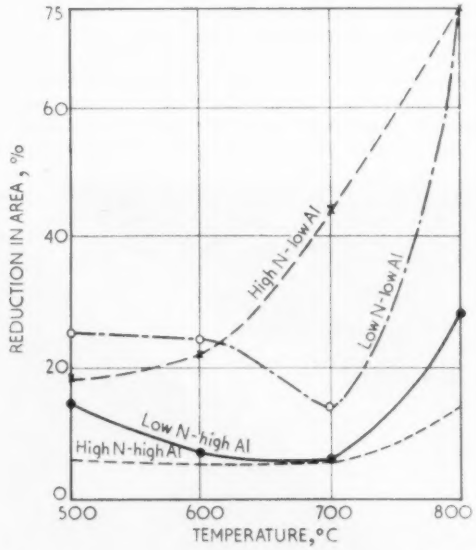


Fig. 11—Temperature *v.* reduction in area of steels as indicated

TABLE V

Results of hot tensile tests on five 8-in. square basic-electric furnace ingots of En 18 steel cast with 0, 6, 12, 18, and 24 oz/ton of Al addition in the ladle; tested in the as-cast condition

No.	Composition, %				Grain size ASTM No.	Temperature, °C	Tensile properties		
	C	Si	Mn	Other elements			UTS	Elongation, %	RA, %
1	0·32	0·45	0·77	1·01 Cr 0·011 Al 0·0082 N 0·0007 N as AlN	3–5	Room temp. 500 600 700 800	45·1 23·7 14·8 8·1 3·6	6·5 16 6·5 13·5 50	3·3 16·3 6·7 14·1 70
2	0·37	0·46	0·87	1·01 Cr 0·019 Al 0·0114 N 0·0014 N as AlN	6–7	Room temp. 500 600 700 800	32·8 24·4 16·8 7·84 3·9	2 9 4 5 42	0·7 20 8 2·6 52
3	0·21	0·44	0·75	0·97 Cr 0·032 Al 0·0083 N 0·0009 N as AlN	6–7	Room temp. 500 600 700 800	34·4 19·2 10·8 5·4 4·1	10 13·5 15 24 28	5 21·9 11·2 18·8 33
4	0·37	0·39	0·76	1·02 Cr 0·035 Al 0·0106 N 0·0008 N as AlN	7–8	Room temp. 500 600 700 800	38 24·8 14·28 8·2 3·8	1·5 12 3 3·7 20	1·2 8·8 4·2 6 24
5	0·33	0·52	0·81	1·01 Cr 0·038 Al 0·0081 N 0·001 N as AlN	6–7	Room temp. 500 600 700 800	30 23 14·4 7·1 4·2	0·75 5 2·5 3·5 1·5	0·88 5 4·7 4·8 5·6

ductile than the other steels with higher carbon contents. This suggests that the carbon content, by its effect on the thickness of the ferrite boundary, is an important factor in determining the susceptibility of a steel to panel cracking.

To relate ductility at high temperatures with the known occurrence of panel cracking, it was decided to carry out hot tensile tests on samples from cracked and uncracked ingots. Test pieces were machined from sections taken from similar positions in cracked and uncracked ingots from two production casts of En 18 steel, made in a basic electric furnace. The results of the tests are given in Table VI.

TABLE VI

Results of hot tensile tests on cracked and uncracked basic electric ingot sections*

Temperature, °C	UTS		Elongation, %		RA, %	
	Cracked	Uncracked	Cracked	Uncracked	Cracked	Uncracked
Room temp.	36·2	35	6·5	10	10	4
Room temp.	38	37	6	15	12	3·2
500	24·1	25·6	5	11·5	8	13·2
500	23·2	25·2	5	10·5	10·4	14·8
500	22·8	24·8	6	11·1	8	14
600	14	17	1	8	2·4	14
600	15·2	19·2	6·3	10·5	4	13·2
600	16·8	14·8	5	6	2·4	11·6
600	14	17·2	3·5	10·5	4	10
600	15·5	16·9	4·2	9·5	3·8	18
700	5·4	7·7	3	†	2·4	8
700	4·4	8·2	†	7	2·4	12
700	8·4	8·3	†	20·5	4·4	4·4
700	8·8	7·9	2·5	†	4	†
800	3·9	4·1	25·5	24	19·6	42
800	3·9	4·2	12·5	†	17·2	46·8
800	4·1	7·4	90	46·5	88	46·8

* Analysis, %

	C	Si	Mn	Al	N	Grain size
Cracked ingot	0·42	0·32	0·81	0·040	0·0057	7
Uncracked ingot	0·37	0·34	0·78	0·014	0·0038	6–7

† Manner of fracture or surface condition prevented observation of gauge marks

From the results in Table VI it can be seen that the ductility of the specimens from the cracked ingot is lower than that of specimens from the sound ingot, at temperatures of the order of 600–700° C. It is interesting to note also that both the aluminium and nitrogen contents are higher in the cracked ingot.

Cracks occur owing to tensile stresses being set up within the ingot during cooling, and should a steel exhibit an abnormally low ductility in a region of high stress concentration it will obviously be more prone to cracking. It is apparent from the results of these tests that steels which are known to be susceptible to panel cracking have low ductilities in the temperature range in which panel cracks are known to occur, and it is also clear that an increase in the aluminium content lowers the ductility still further. It seems logical to suggest, therefore, that if the aluminium used for grain-size control could be replaced, wholly or in part, by some other element, then the region of low ductility might be avoided and resistance to panel cracking increased. Titanium, zirconium, and vanadium have all been previously suggested or used as grain-size control additives in steel manufacture and the next series of hot tensile tests were designed to study the effect of partial replacement of the aluminium by each of these three elements. The steel used was again of En 18 quality, produced in the BISRA arc furnace and the results of the tests are given in Table VII.

The results obtained show that the partial replacement of aluminium by titanium or vanadium improves the ductility of the steel at temperatures in the region of 600° C. The figures for elongation and reduction in area are comparable to, or even slightly better than, those of the uncracked ingot in Table VI. On

TABLE VII

Results of hot tensile tests on En 18 basic electric furnace steels containing Ti, Zr, and V additions as part replacement for Al

Temperature, °C	0·021%Ti–0·021%Al			0·02%V–0·02%Al			0·02%Zr–0·02%Al		
	UTS	Elongation, %	RA, %	UTS	Elongation, %	RA, %	UTS	Elongation, %	RA, %
Room temp.	38	5	2	33·8	5	4	37·8	6	1·6
500	24·5	7	19	22·2	8·7	16	24·3	8·5	17
500	28	13·5	21	21·3	13	17	26·7	10·5	23
500	26·5	14	21	22·1	10	16·8	...	...	...
600	17·5	11·5	22	13·6	11	16	17·1	6	8
600	17	18	33	13·9	11	19·2	16·7	7·5	10·8
600	17	15	23	14·3	11·2	15	...	...	...
700	9·5	17·5	20	7·4	8·7	16	9·6	5	5
700	8·7	10·5	19	8·3	7·5	16	9·2	3·7	8·8
700	9	12·5	19	7·3	10	13·2	8·4	5	4·8
800	4·8	40	41	4	15	12·8	4·4	50	40
800	5	53	50	...	...	...	4·7	45	42

***Note*: All the three steels were fine grained**

the other hand, the zirconium addition is not effective in improving the ductility.

It is interesting to note that additions of titanium and vanadium have been made in works practice for the purpose of controlling grain size. At one works a partial replacement of aluminium by titanium (additions of 0·04%Ti and 0·04%Al gave residual contents of 0·02%Ti and 0·02%Al) gave satisfactory grain-size control and the longitudinal panel cracking which had been experienced previously was eliminated. At another works, satisfactory grain control was obtained by using a vanadium addition alone. A 0·075%V addition to the furnace gave a very uniform grain size and a clean steel, the recovery of vanadium being almost complete. Again it was observed that the trouble due to panel cracking was eliminated.

SUMMARY AND CONCLUSIONS

After an extensive study of the occurrence of longitudinal panel cracking, some of the important factors commonly observed are established. The defect is largely confined to those types of steel which are largely pearlitic with thin continuous grain boundaries of ferrite, and occurs at relatively low temperatures, below the Ac_3 point. It is intergranular in nature, suggesting that the thin boundary of ferrite is incapable of withstanding the stresses developed during cooling. The aluminium and nitrogen contents have pronounced effects on the incidence of the defect.

Hot tensile tests have been carried out to determine the properties of susceptible steels in the temperature range in which this defect occurs. The tests have shown that aluminium markedly reduces the ductility of the steels at temperatures of the order of 600° C, nitrogen having a similar effect only when accompanied by a high aluminium content. It is apparent that the low ductility at these temperatures is the reason for the susceptibility of these steels to panel cracking and this is confirmed by the ductility figures obtained in the tests on samples from cracked and uncracked commercial ingots. The importance of the thin boundary layer of ferrite is shown by the fact that aluminium did not seriously affect the high temperature ductility of one particular steel in which the carbon content was inadvertently low.

Tests on steels in which the aluminium required for grain control was partially replaced by titanium, vanadium, and zirconium have shown that titanium and vanadium are distinctly beneficial in preventing the region of low ductility. Zirconium, however, proved ineffective. Works experience confirms that titanium and vanadium are both effective in providing grain-size control whilst avoiding the danger of panel cracking.

As a result of these studies, the following possible means of reducing the occurrence of panel cracking are suggested:

(1) As the aluminium content of the steel is a major factor, the barest minimum required for satisfactory grain-size control should be used.

(2) The replacement of the aluminium, in part or in full, by elements such as titanium or vanadium will improve the high-temperature ductility of those steels which are susceptible to panel cracking and will, therefore, reduce the incidence of the defect.

(3) If permissible, the ingots should be stripped as hot as possible, and sent to the soaking pits or slowly cooled.

(4) Casting conditions should be carefully regulated to avoid any unnecessary or uneven development of stress in the ingot during cooling.

Acknowledgments

The author would like to thank Dr J. Pearson, Assistant Director, and Mr G. Fenton, Head of Steelmaking Laboratories, of the British Iron and Steel Research Association, for their valuable guidance and help. He would also like to express his thanks to the chairman and members of the Forging Ingots Subcommittee for their suggestions and permission to publish this paper, and to those members who supplied the material for hot tensile tests. The assistance given by Messrs B. Garlick and C. Wheeler, in carrying out experimental work, is gratefully acknowledged.

References

1. F. A. Kirk and S. A. Jarvis: BISRA unpublished report.
2. R. V. Thomas: BISRA unpublished report.
3. BISRA 43rd Steelmaking Conference, September 1954, restricted report.

Mechanism of formation of metal particles in scale on nickel steels†

By K. Sachs

Dr **M. Hillert** and Professor **A. Hultgren** (Sweden) wrote: The author suggests two mechanisms for the formation of the nickel-rich particles found in oxide scale after oxidation of nickel steels, namely, precipitation and entrapment. In our opinion, the former cannot operate during normal oxidizing conditions, and so the latter is the only mechanism for this process. Our conception of entrapment, however, probably differs from the author's, as will be shown later.

To some extent, the oxidation process under discussion resembles the carburization of nickel steels which we have treated earlier,[1] and we shall here use a similar approach. It will be assumed that there is always local equilibrium at the oxide/metal interface.

An isothermal section through the ternary diagram Fe–Ni–O is given schematically in Fig. *A*. The thin lines are so-called 'isoactivity' lines for oxygen, and the indicated directions of these lines follow from the fact that the alloying element nickel prefers the metallic phase to the oxide.[2, 3] The slopes of the phase boundaries are not known, but they are not essential in this connection and were therefore drawn vertically in the figure. It is demonstrated that the higher the oxygen activity, the higher are the nickel contents of coexisting metal and oxide. This fact can be described analytically by an approximate expression[3]:

$$\frac{1}{F} x_{\mathrm{Ni}}^{\mathrm{Oxide}} = x_{\mathrm{Ni}}^{\mathrm{Metal}} = \frac{1}{1-2F} \ln a_O / a_O^0 \quad \ldots\ldots\ldots (1)$$

where $x_{\mathrm{Ni}}^{\mathrm{oxide}}$ and $x_{\mathrm{Ni}}^{\mathrm{metal}}$ are the atomic fractions of nickel in the two phases, F is the partition coefficient for nickel between the coexisting oxide and metal, a_O is the actual oxygen activity, and a_O^0 is the oxygen activity needed to oxidize pure iron to wüstite. For any value of the oxygen activity, for instance a_O^0, one can thus calculate the nickel contents of the coexisting oxide and metal represented by circles in Fig. *A*. An oxide of the same oxygen activity a_O^1 would be supersaturated and could precipitate metal only if its actual nickel content were higher than the value thus calculated from its actual oxygen activity. A supersaturated oxide of this type is represented by a point inside the two-phase field in the diagram (the cross in Fig. *A*). In the same way, a metallic phase is supersaturated and can precipitate oxide only if its actual nickel content is lower than the value calculated from the actual oxygen activity. A supersaturated metallic phase of this type is also represented by a point inside the two-phase field (the star in Fig. *A*).

The full line in Fig. *B* shows the distribution of nickel during the oxidation of a nickel steel. The oxygen activity is highest at the free surface of the oxide and decreases monotonically towards the centre of the specimen. The broken line represents the related nickel content of the oxide calculated from equation (1) and so it must also decrease monotonically. According to this diagram, a nickel-rich metallic phase cannot precipitate inside the oxide layer because the actual nickel content of the oxide (full line) is everywhere lower than the saturation value (broken line). However, precipitation could occur if the oxygen activity were lowered during the process, which may have happened in the oxidation experiments under the protecting box. It certainly happened in the vacuum experiments described on p. 97 of the paper, where "wüstite itself was reduced to iron."

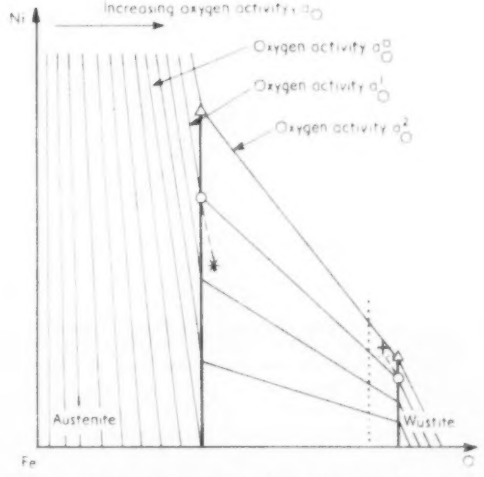


Fig. A—Schematic equilibrium diagram Fe–Ni–O

This discussion seems to rule out precipitation as a possible mechanism for the formation of nickel-rich metallic particles under normal oxidizing conditions. In our opinion, the remaining mechanism, entrapment, can be operative if the oxide/metal interface, which is presumably plane in an early stage of the oxidation process, tends to assume a rougher shape. Protruding parts of the interface may then entrap small parts of the metallic phase by growth sideways. Obviously, this does not agree with the author's statement that "In principle, there is no reason why there should not be a sharp interface between an iron oxide scale containing no nickel and a metallic core correspondingly enriched in nickel." The following two reasons for irregular growth of a sharp interface may be suggested.

(1) Wagner[4] has recently examined the stability of a plane oxide/metal interface by considering the diffusion of the less noble component A in the oxide and in the metallic phase. He found that a plane interface is stable if the quantity

$$q = \frac{N_A^*}{1 - N_A^*} \frac{D' V''}{D^{*''} V'} \quad \ldots\ldots\ldots (2)$$

is larger than unity. N_A^* is the mole fraction of A in the metallic phase at the oxide interface, D' and V' are the interdiffusion coefficient and the molar volume of the metallic phase respectively, and $D^{*''}$ and V'' are the self-diffusion coefficient of A in the oxide at the interface and the volume of the oxide involving one mole of A respectively. If q is evaluated at 1 100°C for a steel with 1·5% nickel, it is found to be less than 0·001 at the beginning of the oxidation, indicating a strong tendency for any small deviation from a plane interface to develop further. The entrapment mechanism thus seems quite probable on these theoretical grounds.

† *JISI*, 1957, vol. 187, Oct., pp. 93–104.

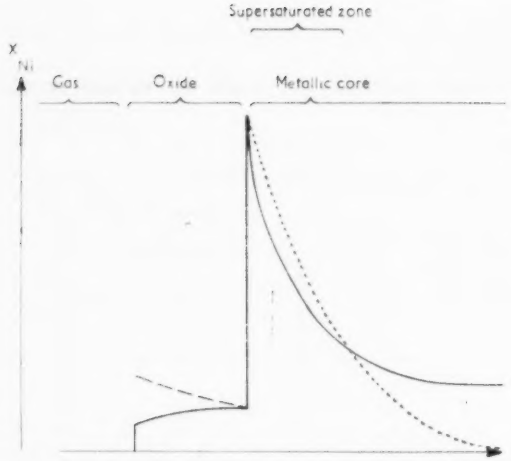


Fig. B—Distribution of nickel during oxidation. Full line = actual nickel content, broken and dotted lines = nickel content corresponding to the actual oxygen activity

The small deviations from a plane interface, necessary for starting the development of a rough shape, may be caused by grain boundaries and other inhomogeneities in the material or by the following mechanism of internal oxidation, which by itself is a mechanism of changing a sharp interface.

(2) In the metallic core oxygen diffuses from the oxide/metal interface towards the centre, producing a monotonically decreasing oxygen activity in this phase also. The dotted line in Fig. *B* represents the related nickel content for the metal, calculated from equation (1). This line must be much flatter than the full line representing the actual nickel content, because oxygen diffuses much more easily than nickel in austenite.[5] There is thus a zone where the dotted line lies above the full line, although it finally decreases to very low values. Consequently, the metal is supersaturated in this zone and can here precipitate oxide. The numerous small oxide particles visible in the metal matrix in Figs. 1, 4, and 7 are probably the result of such a mechanism of internal oxidation.

Internal oxidation has previously been observed and treated theoretically by a number of authors, and this literature was recently reviewed.[6] It should be noted, however, that the alloys considered have had a high content of the noble component and are usually low in the less noble component, which forms the oxide. The descriptions of the mechanism for internal oxidation given by these authors are therefore not applicable to the present case, where the content of the noble component is low (1·5%). Instead, the mechanism for internal oxidation of this new kind described in the preceding paragraph resembles the formation of new crystals ahead of the advancing solid/liquid interface during the cooling of a liquid alloy, as described qualitatively by Hultgren[7] and recently in more detail by Wagner.[8] The conduction of heat plays the same role in the solidification process as the diffusion of oxygen in our case of internal oxidation.

AUTHOR'S REPLY

Dr **K. Sachs** (GKN Group Research Laboratory) wrote: Professor Hultgren and Dr Hillert point out that precipitation of nickel on particles some distance from the interface implies that it has been dissolved at the interface in wüstite of low oxygen activity and low nickel saturation concentration, and then precipitated in a zone where the oxygen activity and nickel saturation concentration are higher. Their contribution is a detailed exposition of the theoretical difficulty of the precipitation explanation to which I drew attention in the paper; however, I indicated that the mechanism is nevertheless feasible and I shall try and demonstrate this with the aid of Figs. *A* and *B*.

Figure *B* does not represent the distribution of nickel during oxidation at all accurately, because it neglects the influence of the nickel-rich particles embedded in the scale. This has a considerable influence on the curves, as I shall show later; one effect is that throughout the zone where nickel is present in the scale the wüstite is fully saturated with nickel. Thus the theoretical difficulty is to explain why nickel should diffuse from one point in a saturated solution to another when by definition there cannot be a nickel activity gradient.

To explain this I have referred in the paper to the spheroidization of pearlite as an analogy. Particles of cementite are embedded in saturated ferrite; they disappear and coarser particles of rounded shape take their place. Evidently carbon has gone into solution and has been precipitated elsewhere although the ferrite is saturated throughout. The usual explanation is that the fine lamellæ have a higher surface energy than the coarser rounded particles, and that there is a slight, probably metastable, increase in solubility near the high-energy surface so that some carbon is dissolved; this can then diffuse to a point where precipitation from ferrite on a growing cementite particle has reduced the carbon concentration.

With this sort of reasoning in mind, let us consider some nickel-iron particles in equilibrium with wüstite. If the compositions of the two phases correspond to the triangles in Fig. *A*, the oxygen activity at equilibrium may be designated a_O^2. Let us assume that the particles are broken down to such a small size that the surface energy per mole makes a significant contribution to their free energy; clearly their molar free energy will be higher than that of massive particles, and their solubility will increase, which can be expressed as a decrease in the oxygen activity of the wüstite with which they are in equilibrium. For the sake of convenience, let us suppose that the oxygen activity falls to a_O^1, the nickel and oxygen concentrations of the metal phase remaining constant. The wüstite in equilibrium with these metal particles will have the same nickel content as that in equilibrium with massive particles, but the oxygen activity is only a_O^1; since the solubility of the metal in wüstite has increased, the wüstite will have a lower oxygen concentration, indicated by the intersection of the nickel content and the line for a_O^1. Thus the effect of small particle size is to produce metastable wüstite at lower oxygen concentrations, and this has been indicated in Fig. *A* by a dotted line parallel to the boundary of the stable wüstite field. An oxide represented by the cross on Fig. *A* would be metastable as a single phase and, as stability is approached, nickel is precipitated at points where it will not make a significant contribution to the surface energy, i.e. where it will not create a fresh surface.

A less rigorous but correspondingly more imaginative treatment would consider what happens to a very small group of nickel atoms in the austenite lattice when the iron is oxidized. The austenite lattice has disappeared; they are suspended in space, surrounded by wüstite. There are not enough of them to form a respectable nucleus of metallic nickel, so that the 'small particle' treatment does not apply. Either the nickel atoms will

attach themselves to the wüstite lattice in some way or the wüstite will form a fresh surface around the nickel; thus the nickel will be either a coherent or an incoherent metallic inclusion in the oxide crystals, depending on the energy balance. The freshly formed surface in the wüstite lattice represents a zone of extremely high strain or surface energy. Similar zones will cluster together until a ' small particle ' of nickel is formed, or they will migrate separately to a metal/oxide interface which may be regarded as a sink for this kind of defect.

A fair amount of experimental evidence on the distribution of nickel in the scale is presented in an earlier paper.[9] A schematic representation of the nickel distribution is shown in Fig. *C*, drawn to a different scale from that used in Fig. *B*. The curves in Fig. *B* are shown on the diagram, and the nickel in the metal particles is also included. The oxide is very thick relative to the surface layer enriched in nickel, and the predominant feature is a peak in the overall nickel concentration at some distance from the scale/metal interface. In this zone the oxygen activity and the associated nickel concentration of the metal particles should be fairly high (Fig. *A*). If these particles had formed by the entrapment mechanism, the overall nickel content should not differ substantially from the bulk nickel content of the steel and the number of metal particles of high nickel content should be correspondingly small. In fact, the overall nickel content may be as much as four times that of the steel core, and microscopic examination reveals a very large number of metal particles. It is evident that nickel has travelled outward from the core over a distance of about 2 mm. The fact that the metal particles grow after their formation in the scale is demonstrated in Figs. 13–15 of the paper under discussion.

Oxidation under a protecting box lowers the oxygen partial pressure in the atmosphere and produces a scale with a shallower activity gradient; it may be regarded as producing an oxide layer with some of the properties of very thick scale in a shorter time. There is no reason to believe that the oxygen activity was lowered suddenly at any point during oxidation under the protecting box. The same applies to the vacuum experiment described on p. 97. The furnace was evacuated before heating and some wüstite was reduced to iron while equilibrium was being established. Thus the effect of vacuum heating was to lower the oxygen activity to a_O^0 in Fig. *A*; but this was done at the beginning of the experiment and it was this wüstite which attacked the surface of smooth nickel wires to produce the oxide penetration, shown in Fig. 12 of the paper. Thus transfer of nickel took place across wüstite in equilibrium, initially at least, with pure iron. It follows from the thermodynamic considerations illustrated in Fig. *A* that a stable solution of nickel in wüstite cannot be formed. However, dynamic equilibrium implies that nickel passes back from oxide to metal at the same rate as it enters the oxide; it does not follow that the atoms must necessarily be deposited at the same site from which they initially entered into ' transient ' or metastable solution. It is this transfer of nickel across saturated wüstite, involving no more than statistically probable local deviations from equilibrium, which plays an important part in the mechanism of formation of the metal particles in the scale. This may be stretching the concept of precipitation a little. I used the term because it correctly conveys the impression that the metal particles grow by deposition of metal from the wüstite.

Entrapment proceeds by preferential oxidation of the grain boundaries and by the spreading, perhaps also the lateral growth, of oxide globules which may well have formed by the mechanism suggested by Hillert and

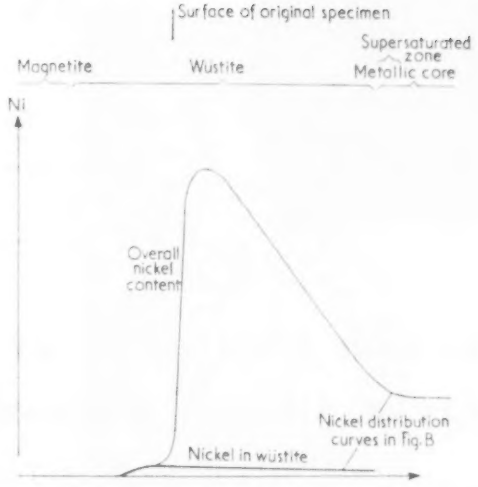


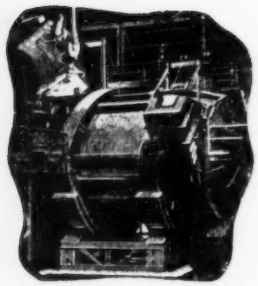
Fig. C—Distribution of Ni in the scale layer

Hultgren. This process forms large metal particles which can be seen under the microscope. I have also used the term ' entrapment ' for the process by which small groups of nickel atoms are caught in the advancing wüstite because the two processes appear to be similar in principle; entrapment on the atomic scale has been shown above to lead to migration of nickel through wüstite i.e. the ' precipitation ' mechanism.

My statement that there is no reason in principle why the boundary between the oxide and metal phase should not be straight was an amplification of the preceding sentence: " The thermodynamic reason for the existence of the particles does not explain their form and distribution nor the mechanism of their formation." In order to explain the formation of metal particles in the scale it is necessary to include considerations outside the scope of thermodynamics i.e. the kinetics of the reaction. Both types of entrapment described above occur because the diffusion of iron through the oxide, which determines the rate of advance of the oxide, is much faster than the interdiffusion rate of iron and nickel in the metal: nickel is caught in the scale and stabilizes large metal particles or migrates to suitable surfaces, because it cannot get away into the core of the metal. The reason why q in equation (2) is about 0·001 is that $D'/D^{*\prime}$ is about 10^{-5}, i.e. that iron diffuses in oxide much faster than nickel in austenite. Thus the instability of the interface predicted by Wagner's equation finds its expression in the formation of metal particles in the scale.

REFERENCES

1. A. HULTGREN and M. HILLERT: *Jernkont. Ann.*, 1953, vol. 137, pp. 217–223.
2. M. HILLERT: *Ibid.*, 1952, vol. 136, pp. 25–37.
3. M. HILLERT: *Acta Met.*, 1955, vol. 3, pp. 34–3
4. C. WAGNER: *J. Electrochem. Soc.*, 1956, vol. 103, p. 571.
5. C. E. BIRCHENALL: " Atom Movements," p. 112: 1951, Cleveland, American Society for Metals.
6. F. N. RHINES: *Ibid.*, p. 174.
7. A. HULTGREN: *Jernkont. Ann.*, 1930, vol. 114, pp. 95–152.
8. C. WAGNER: *Trans AIME*, 1954, vol. 200, pp. 154–160; *J. Met.*, 1954, vol. 6, Feb.
9. K. SACHS: *JISI*, 1957, vol. 185, pp. 348–357.



IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group

Vacuum treatment of steel by the Bochumer Verein stream degassing process

By A. Tix, G. Bandel, W. Coupette, and A. Sickbert

SYNOPSIS

A new method of degassing steel is described which has the main advantage of reducing hydrogen contents and thus producing flake-free forgings. The low total oxygen and inclusion content of the vacuum-treated steel leads to an improvement in toughness. The method can be applied to the degassing of large quantities of steel and to the production of small ingots of high-alloy steels. It has been in use at the Bochumer Verein since 1952 for all heavy forging ingots. 1674

THERE ARE CERTAIN LIMITS to the removal, by ordinary metallurgical methods, of those gases which have a harmful effect on certain grades of special purpose steels. As in the hot extraction method of determining the gas contents of molten steel, use can be made of the relationship between gas solubility and pressure to reduce the gas content of steel during actual operations.

Figure 1*a* shows the extent to which the hydrogen, oxygen, and nitrogen contents of molten iron can be reduced as the pressure is reduced. Oxygen solubility is strongly affected by the carbon content of the steel as well as by the pressure; the oxygen content is therefore denoted by the product C×O, which is roughly constant for a given pressure. Other alloying elements also affect gas solubility and give rise to deviations from the graphs shown in Fig. 1*a*.

The original aim at Bochumer Verein AG in using a vacuum treatment was to produce heavy forgings free from flakes and was thus mainly a question of removing hydrogen. Vacuum-melting processes have so far been limited both from the viewpoint of size of melt and cost of the process. Bochumer Verein began tests with 60-ton heats at the beginning of 1950, which led, in 1952, to the vacuum stream degassing process making possible the degassing of large quantities of steel up to 150 tons and over.[1] A simplified graph is shown in Fig. 1*b* of the gas contents obtained in ingots up to 150 tons using vacuum stream degassing, compared with those obtained by ordinary air casting and high-vacuum melting. As a result of the favourable kinetic conditions in vacuum stream degassing it was possible to approximate closely to the theoretical hydrogen equilibrium at 1–10 mm Hg as shown in Fig. 1*a*, lower gas contents than this were generally not obtained with the vacuum-melting process even after several hours' treatment at 10^{-3} to 10^{-5} mm Hg. The pressure equilibrium point for the product C×O has not yet been attained with the vacuum stream degassing method although there has been considerable evolution of CO. The departure from equilibrium at lower pressures is more marked in the vacuum-melting process mainly because oxygen is taken from the crucible material. The removal of nitrogen by the vacuum stream degassing method at 1–10 mm Hg is not as successful as in the vacuum melting process.

The process that has been used most frequently at Bochumer Verein AG has been the vacuum casting of heavy ingots, the method is shown diagrammatically on the right-hand side of Fig. 2. The advantages of this process are the avoidance of time or temperature losses during manufacture, and the preventing of the liquid steel from reacting with air and the refractory lining. These advantages distinguish the vacuum casting of ingots from the vacuum-melting process and from all other processes where the steel comes into contact with air or refractory materials during and after degassing.

Stream degassing from ladle to ladle, shown on the left-hand side of Fig. 2, is used for rolled steel and steel castings. Vacuum-treated steel has remarkably good fluidity and even thin-walled sections of castings show no porosity, which is especially important with 13%Cr steels.

Figure 3 is a photograph of the edge of a casting stream showing the droplet size that occurs with vacuum stream degassing. This can be seen to better advantage in motion on ciné-film. Degassing begins when the casting stream breaks up into droplets on entering the vacuum chamber. The large steel surface of the falling droplets and the violent move-

Manuscript received on 1st December, 1958.
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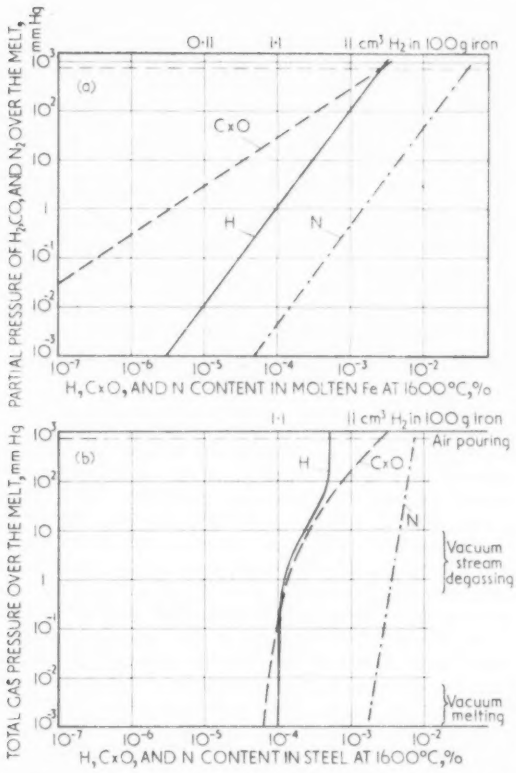
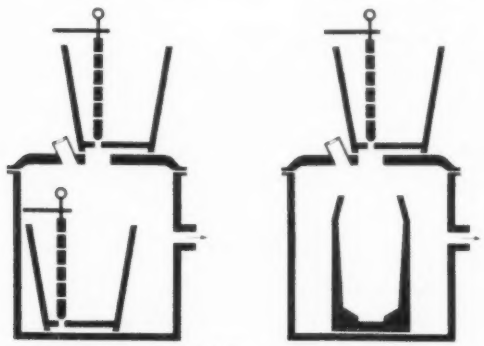

PARTIAL PRESSURE OF H₂, CO, AND N₂ OVER THE MELT, mm Hg
O·II
I·I
II cm³ H₂ in 100 g iron
(a)
C x O
H
N
H, C x O, AND N CONTENT IN MOLTEN Fe AT 1600°C, %
TOTAL GAS PRESSURE OVER THE MELT, mm Hg
(b)
Air pouring
Vacuum stream degassing
Vacuum melting
H, C x O, AND N CONTENT IN STEEL AT 1600°C, %

Fig. 1—(*a*) Theoretical gas contents in pure molten iron at different pressures (*b*) Actual gas contents in steel at different pressures

ment within them cause rapid and almost complete degassing in spite of the high casting speed of up to 10 tons/min and the short time for which the steel is exposed to the vacuum. An important effect on the speed of degassing is the fact that the ferrostatic pressure in the falling casting stream is zero.

As well as stream degassing, simple ladle degassing was also used, in which the fully charged ladle is placed in the vacuum vessel and exposed to vacuum. In contrast to stream degassing, this



(*a*) Degassing from ladle to ladle (*b*) Vacuum ingot casting

Fig. 2—Stream degassing of steel

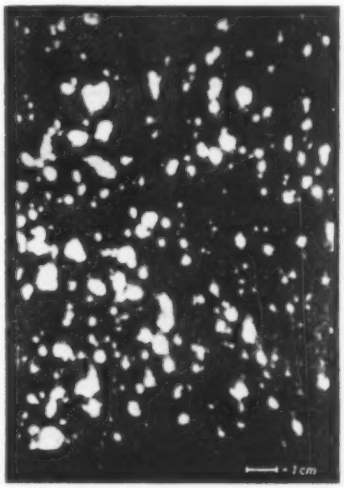


Fig. 3—Size of droplets during stream degassing

ladle degassing has relatively little effect. An increase in the degassing effect can be achieved by stirring the steel in the degassing vessel so that during degassing all parts of the melt pass through the region of low ferrostatic pressure at the surface. With the additional use of a reducing slag and by maintaining its reducing nature (by adding reducing agents if necessary) thorough mixing and intense reaction of the steel with the slag is achieved that is not otherwise obtained in the normal method of steelmaking.

In the following paragraphs the gas contents obtained with stream degassing are compared with the contents usually obtained with air casting.

On the average, stream degassing at 1–10 mm Hg gives hydrogen contents of 1·8 ml/100 g, corresponding to 1·6 p p m in the liquid steel (Fig. 4). This was determined by the tin melting method; sampling was carried out by sucking with a quartz pipette and quenching with mercury in a U-tube. With carbon and low-alloy steels the hydrogen contents obtained in liquid steel after degassing, fall during forging or rolling and subsequent tempering to below 1·5 ml/100 g throughout the whole cross-section, even with large-diameter ingots. Without degassing, the liquid steel contains between 4 and 8 ml/100 g of hydrogen depending on whether it is electric or open-hearth and whatever metallurgical treatment may have been applied. With air-casting, hydrogen contents at the core of solid ingots are found to be of 3 ml/100 g and over and only decrease towards the edge of the ingot after heat treatment. There is thus the danger of flake-formation if the ingot is left in air immediately after forging.

The reduction in oxygen content as a result of stream degassing is at its highest with soft rimming steels, as would be expected. In this case the oxygen content is reduced to about one-fifth of the initial content. The absolute values obtained are lower the higher the carbon content of the steel (Fig. 5). With killed plain carbon and low-alloy electric

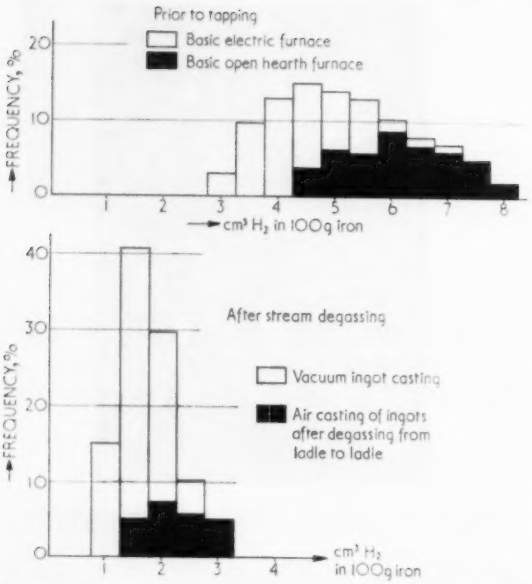

Prior to tapping
Basic electric furnace
Basic open hearth furnace
FREQUENCY, %
cm³ H₂ in 100g iron
After stream degassing
Vacuum ingot casting
Air casting of ingots after degassing from ladle to ladle
FREQUENCY, %
cm³ H₂ in 100g iron

Fig. 4—Hydrogen content before and after vacuum stream degassing

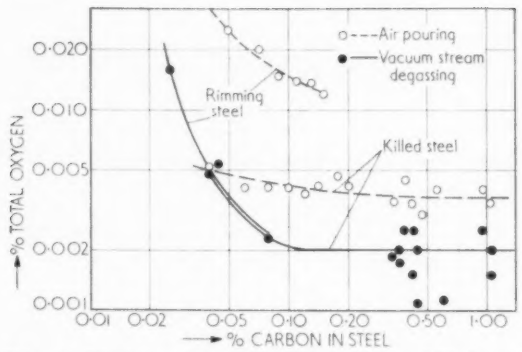
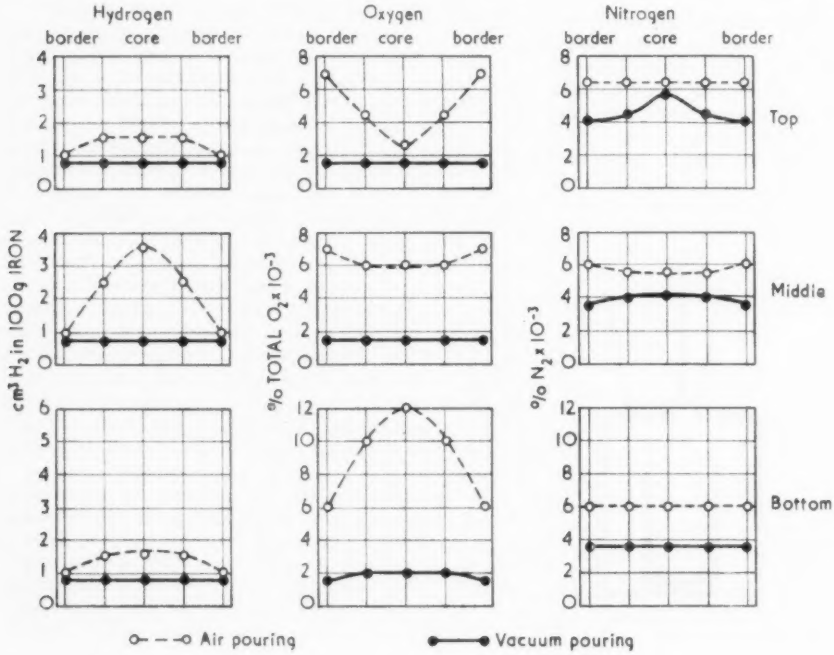


Fig. 5—Oxygen and carbon contents in killed and rimming steels

and O H steels (over 0·1%C) the total oxygen contents as determined by the hot extraction method drop, on the average, to 0·002% with stream degassing. This corresponds to an inclusion content of about 0·004% or 40 g/ton. Steels for heavy forgings are not generally deoxidized with aluminium or only with very little; this gives a total oxygen content of 0·004% for electric steel and 0·008% for O H steel.

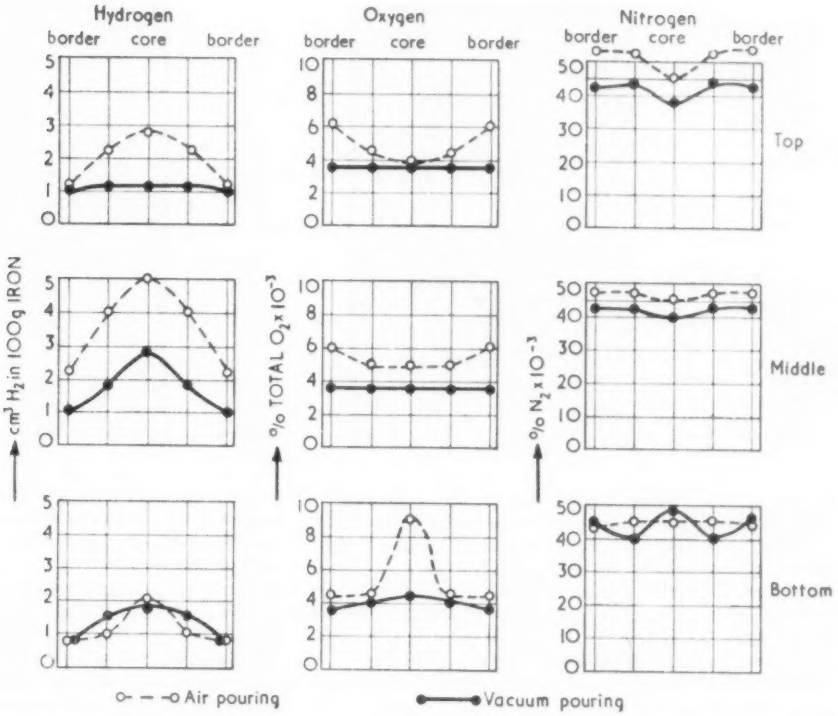
Vacuum stream degassing will reduce the oxygen content to less than half that for aluminium-killed steels; indeed, the average reduction with these grades is 50% and is up to 80% for rimming steels. Figure 5 shows the total oxygen content for killed and rimming mild steels and ordinary carbon steels, and also the Ni–Cr–Mo steel used in Germany for making rotors and a ball-bearing steel with 1–1·5%Cr.

An important observation is that the vacuum casting of ingots not only reduces the oxygen content but also distributes it regularly along the length and cross-section of the ingot. Figure 6 shows the distribution of hydrogen, oxygen, and nitrogen in vacuum-cast and air-cast carbon steel (0·35%C) from the same O H heat. Similar low values and the same regularity can also be demonstrated in the Ni–Cr–Mo steel used in Germany for rotors (0·28%C, 2·0%Ni, 1·3%Cr,



Analysis,	%
C,	0·35
Si,	0·38
Mn,	0·68
Al	0·004

Fig. 6—Gas contents in 21-ton ingots, from the same melt



Analysis,	%
C,	0·22
Si,	0·42
Mn,	0·69
Cr,	11·90
Mo,	1·02
V	0·35

Fig. 7—Gas contents in 8-ton ingots, from the same melt

0·45%Mo, 0·1%V), e.g. by examining the axially drilled core of a large inductor shaft of 65·6 tons forged weight having a total length of 10·9 m made from a 100-ton vacuum ingot. Figure 7 shows the distribution of the gas content in 8-ton ingots, cast in air and *in vacuo*, of high-alloy 12%Cr–Mo–V steel with high creep resistance at elevated temperatures. The effect of degassing is less with the high Cr content; in this case the avoidance of oxidation of the casting stream is decisive.

The reduction in nitrogen content by stream degassing (Fig. 8) varies according to the grade of steel as is the case with oxygen. Whereas there is a reduction of about 35% with plain carbon steels, this drops to 10–25% for soft steels, depending on whether they are rimming or killed. In the 12%Cr–Mo–V steel mentioned, there is, as has already been shown in Fig. 7, a reduction of about 10% in the nitrogen content. With austenitic steel, vacuum stream degassing causes hardly any reduction in the nitrogen content, especially when it contains titanium.

As far as steel properties are concerned, the following advantages were obtained by vacuum stream degassing, based on a production since 1952 of 78 000 tons of vacuum-treated steel, especially of 670 rotors and inductor shafts.

The removal of the hydrogen content by stream degassing, which is particularly important for heavy forgings of steel with a tendency to flake, has led

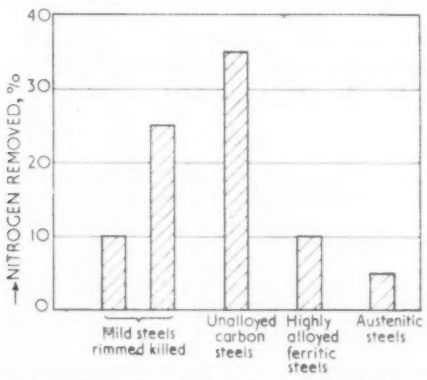


Fig. 8—Nitrogen removal by vacuum stream degassing

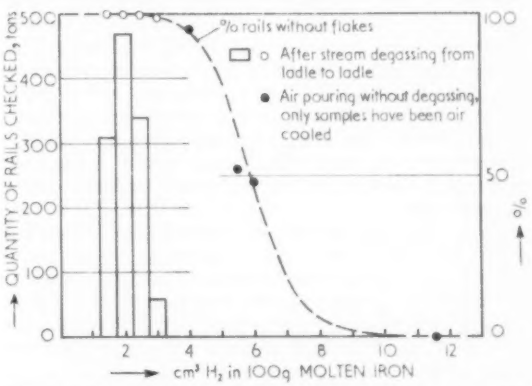
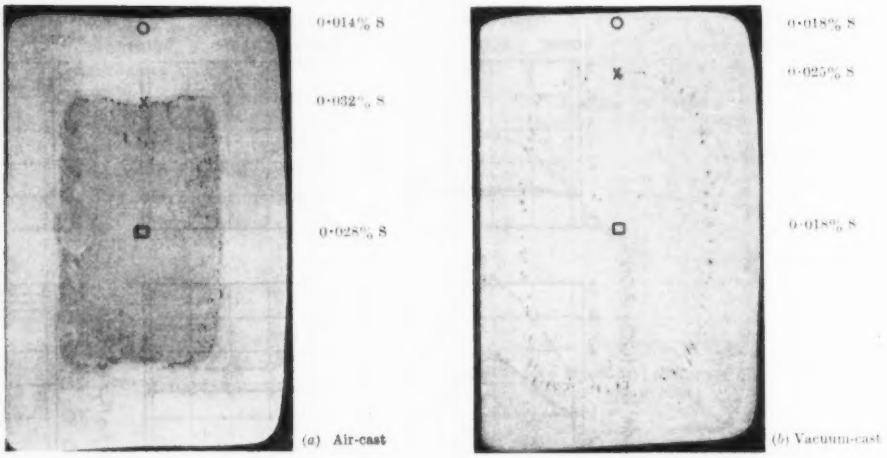

% rails without flakes
o After stream degassing from ladle to ladle
• Air pouring without degassing, only samples have been air cooled
QUANTITY OF RAILS CHECKED, tons
%
cm³ H₂ in 100g MOLTEN IRON

Fig. 9—Flakes in high-strength rails, cooled in air after rolling



Analysis, %
C, 0·05
Mn, 0·27
P, 0·010
S, 0·020
Si nil and Al nil

Fig. 10—Baumann prints of the centre of two ingots showing the reduction of segregation

to complete freedom from flakes in all tests and in current production. This has been achieved not only with forgings of up to 1 600 mm dia. without additional heat-treatment for hydrogen diffusion, but also with heavy rolled blooms, which are cooled in air directly after rolling. In general, a hydrogen content of less than 3 ml/100g in the liquid steel is sufficient to obtain freedom from flakes.

This is also seen in the following example of particularly flake-sensitive, high-strength rails (Fig. 9). No flakes were found in 1 200 tons of rails made of steel vacuum-degassed by casting from ladle to ladle after cooling in air directly after rolling. On the other hand, up to 100% of rails made from melts cast without vacuum treatment, having the same high initial hydrogen contents, exhibited flakes, unless they were cooled slowly in a covered pit as usual.

The reduction of the oxygen content in soft rimming steels leads to a considerable limitation of ingot segregation and a corresponding increase in the degree of purity. This is shown in Fig. 10 by Baumann prints of the centre of two ingots. Both ingots are from the same melt. The ingot on the left was cast in air in the ordinary way and reveals the normal segregation pattern for rimming steels. The ingot shown on the right was cast *in vacuo* and held there for a certain time after casting. This has given a segregation pattern which is somewhat comparable to that for semi-killed steels. As has already been stated, the vacuum treatment of rimming steel reduces the oxygen content to one-fifth and also causes regular oxygen distribution throughout the ingot. This means that rimming vacuum steel has advantages over semi-killed steel, and can be particularly important for the production of heavy slabs for wide strip.

From the point of view of improving technological properties, especially the toughness of vacuum-treated steel, besides removing the risk of flake cracks, the following observations have been made:

(1) A reduction in elongation and a reduction in area as a result of high hydrogen content does not occur with vacuum forgings.

(2) Although ghost lines can still be seen in the Baumann print of forgings made of killed vacuum-treated steel, nail heads and premature fracture no longer occur in tensile tests of radial drill cores, since no cracks occur due to the low gas content in the segregation zone.

(3) The low total oxygen and inclusion content of vacuum-treated steel also leads to an improvement in toughness. A reduction in the transition point of the notch impact toughness/temperature curve occurs only under very limited conditions, of the order of 20° C. The considerably stronger effect of the degree of forging and heat treatment mask this effect in heavy forgings.

Vacuum treatment obviously does not take the place of careful metallurgical processing, and can only have its full effect in conjunction with such an approach. Certain types and concentrations of inclusions cannot be removed even by vacuum treatment.

A forging of 12%Cr–Mo–V steel with high creep resistance at elevated temperatures is shown in Fig. 11 as an example of regularity in technological properties. This is a turbine rotor with a forged weight of 26·3 tons, made from a 40-ton vacuum ingot. The lower half of the figure gives the technological data for the axial drill core of the rotor through the length of the rotor. The rotor could have been used after ultrasonic testing without taking borings, as could many similar forgings from this vacuum steel.

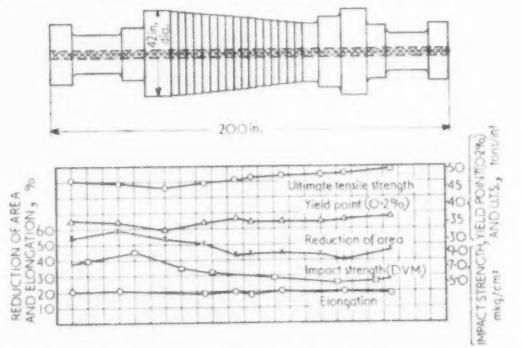


Fig. 11—Forging in 12%Cr–Mo–V steel. Lower half of figure gives properties of an axially drilled core

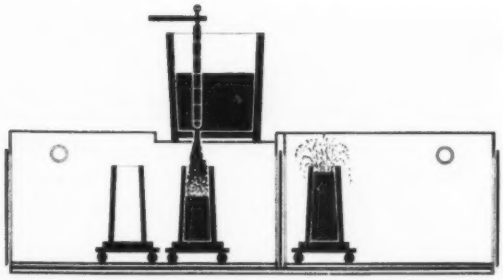


Fig. 12—Diagram showing the continuous vacuum-casting method

At Bochumer Verein AG vacuum stream degassing is used for those purposes which are important for the production programme. In a modified form vacuum stream degassing can easily be adapted for other requirements, e.g. on the one hand, for the production of tonnage steel, and on the other, for high-alloy steels in small ingots. This is demonstrated in the following examples.[2]

If vacuum treatment is to be applied to a large proportion of the output of a steelworks or to its total production, then equipment is recommended which offers continuous stream degassing without considerable work and expenditure. For example, as shown in Fig. 12, the ingots can be introduced into the degassing chamber and removed from it at the side through locks. An installation is shown in which rimming steel can be cast *in vacuo* and, after treatment, solidify *in vacuo*. It can also be used for killed steels.

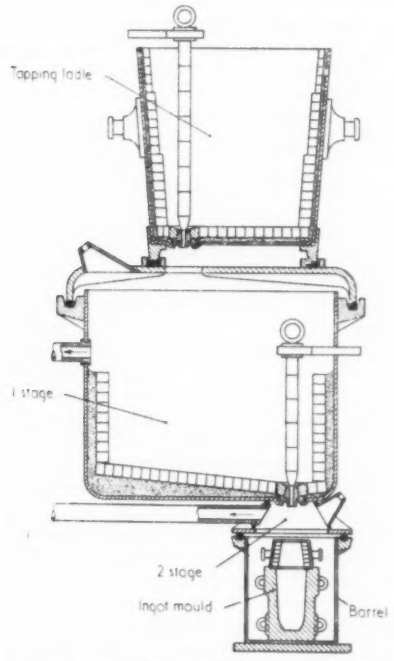


Fig. 13—Apparatus for casting small ingots under vacuum

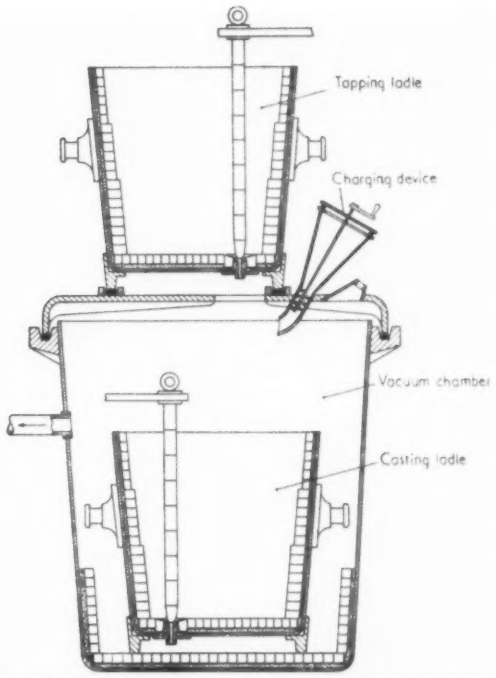


Fig. 14—Charging device for additions in the steel stream

The Bochumer Verein process of multi-stage degassing (Fig. 13) represents a combination of vacuum ingot casting and ladle-to-ladle degassing. It provides for the continuous degassing of rolling-mill ingots at very low pressures, without disturbance from the dispersion of the casting stream. This plant is recommended for especially high-grade steels with exceptional requirements as far as degree of purity is concerned.

The addition of alloying and deoxidizing agents during vacuum stream degassing is carried out in special cases through a lock, as shown in Fig. 14.

Experience with vacuum stream degassing has shown that this process can give gas contents in the steel which are otherwise unattainable in large-scale production. This refers particularly to hydrogen and oxygen. The technological properties which can be achieved, together with their consistency and in particular the certainty of avoiding flakes, not only justify the introduction of the process, but make it indispensible for the production of heavy high-grade forgings. The process is well suited for making considerable improvements to rolled steel and can be adapted to the flow of operations in mass production without any considerable expenditure.

References

1. A. Tix: *Stahl Eisen*, 1956, vol. 76, pp. 61–68, also *AIME Elec. Furn. Steel Conf. Proc.*, 1955, vol. 14, pp. 70–84. This reference has an extensive bibliography.
2. A. Tix and W. Coupette: Paper given at the First International Congress on Vacuum Processes, Namur, June, 1958.

Vacuum-induction melting

By F. N. Darmara, J. S. Huntington, and E. S. Machlin

SYNOPSIS

A brief history of vacuum-induction melting is given and the equipment required for large-scale operation, including a 5 000-lb furnace, is described. Basic principles of the process are discussed and examples are given of improvements obtained in the physical properties of high-temperature alloys and certain steels. 1668

INTRODUCTION AND HISTORY

THE HISTORY of production vacuum melting is another example of a familiar pattern: the adaptation to practical use of basic ideas conceived years ago. A US patent was granted before 1867 for a vacuum furnace complete with vacuum locks, and other patents were granted in the 1890's for furnaces, as well as for a degasification technique. There is no record of a practical furnace until that developed by Arsem in 1907, which became the first useable tool for studying metallurgical reactions in the molten state *in vacuo*.[1]

The first production vacuum-melting operation arose from experiments conducted during World War I by Dr Wilhelm Rohn in Germany. His work on Ni–Cr alloys led to the founding of Heraeus–Vacuumschmelze AG, which produced vacuum-melted heats up to 650 lb in resistance-heated furnaces. Rohn reported decreases in the gaseous content of electron-tube alloys and increased cleanliness and workability for Ni–Cr alloys. The size of the furnace was increased during the 1920's after induction melting was incorporated, and, beginning in 1939, 10 000-lb heats were produced. Unfortunately the development of high-speed, high-vacuum pumping did not match progress in furnace design; consequently, the fullest benefits of the process could not be realized, since pressures of less than 2 mm Hg could not be maintained.

Concurrently with Rohn's work, laboratory units sprang up throughout Europe and the USA; while these were able to use an improved degree of vacuum made possible by the newly developed oil-diffusion pumps, the melt size was usually limited to a few pounds.

The impetus of World War II, with its requirements for high-vacuum pumping installations for atomic-energy work and for the production of penicillin, and for blood-plasma processing, brought about the development of mechanical and oil-diffusion pumps offering much greater speed and reliability. As a result, metallurgists at last had at their disposal pumping equipment to meet their needs for larger melts at lower pressures.

It is interesting to note, however, that the vacuum-melting industry did not grow as rapidly as might have been expected in the first five years after the war. By 1951 only a few companies had what could be considered production installations. Their activities centred around the production of pure gas-free copper, iron, and alloys used primarily in the electron-tube industry, and the sizes of heats were 300 lb at most.

About this time, the Utica Drop Forge and Tool Corporation,* a major supplier of bucket forgings for jet engines, was experiencing difficulty in obtaining air-melted high-temperature alloy bar stock with properties consistent from heat to heat. This was a serious problem, since not only forgeability but also stress-rupture life varied through wide limits, with the result that scrap rates were excessive and production schedules were impossible to meet. The alloys with the widest scatter were those nickel-based alloys containing appreciable quantities of aluminium and titanium present as precipitation-hardening agents. While the apparent chemistry met specifications in every detail, stress-rupture life varied widely from heat to heat, with an alarming percentage well below the specification limits. Because of the extremely active nature of aluminium and titanium, it was felt that vacuum melting might possibly afford a means of assuring that these elements were prevented from oxidizing in an uncontrolled manner during the alloying and the pouring of the ingot.

A small experimental furnace was built in 1952 in which Waspaloy was melted in 6-lb heats and tested. The results were most gratifying, not only because more consistency in physical properties was obtained, but also because the average stress-rupture life was increased by a considerable amount. A J48 engine was fully bladed from metal melted in this furnace, one bucket per heat, and the wheel was put through standard tests as well as other more stringent ones. The results were excellent. The consistency of results with this small furnace led to speculation about what could be expected from larger furnaces. Speculation led to action: in 1953, 100- and 300-lb furnaces were acquired and installed. Gratifyingly, it was found that heats from the larger furnaces gave no greater scatter of results. As melting practices were improved, properties continued to increase to the point where the specification for Waspaloy was raised considerably.

It was not long before the distinct advantages of vacuum melting led engine manufacturers to specify vacuum-induction-melted alloys for buckets and blades. The demand for this material rose sharply, and larger furnaces were installed in Utica as well as in several other companies in the eastern USA.

Manuscript received on 24th November, 1958.

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* Now a division of the Kelsey-Hayes Company

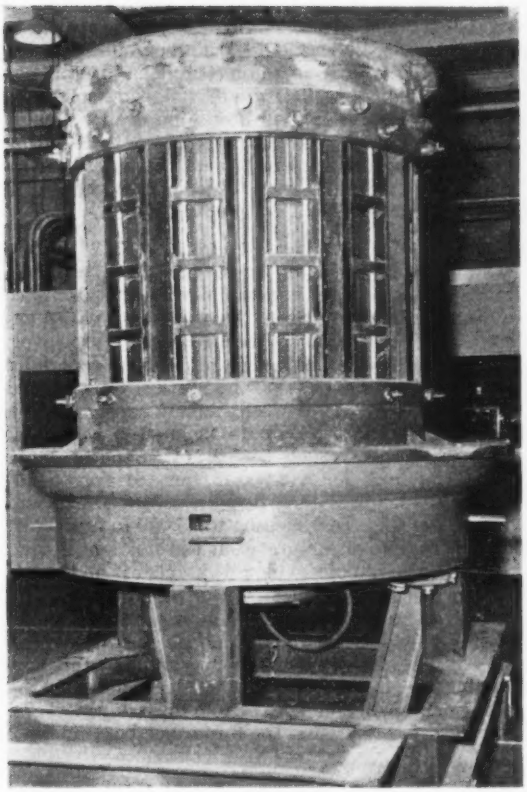

Fig. 1—Induction coil assembly for 5 000-lb furnace showing vertical magnetic yokes

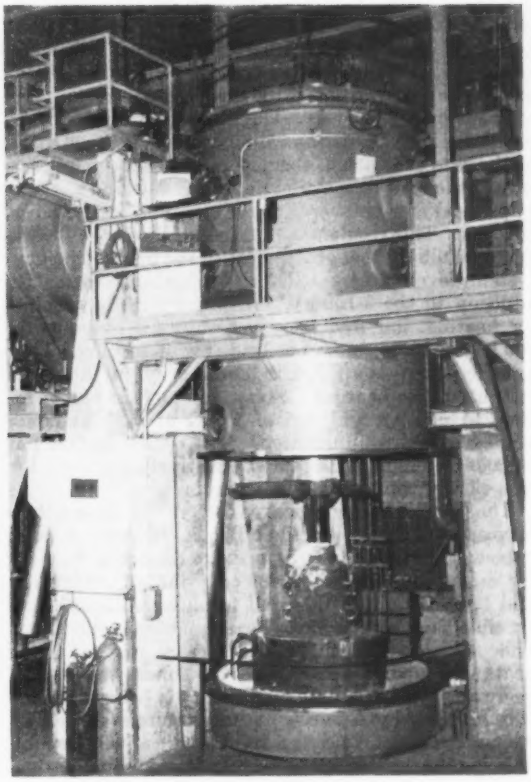

Fig. 2—Mould chamber for 5 000-lb furnace with mould table and cover in lowered position

Before long, improved alloys were developed, notably Udimet 500*, which had not only superior stress-rupture properties but also tensile strength at elevated temperatures, which made it extremely attractive to designers of structural members in the missile field.

As furnace equipment became available in larger sizes, interest was aroused in fields other than high-temperature alloys; today large quantities of bearing steels and high-strength tool steels are also being melted.

EQUIPMENT FOR LARGE VACUUM FURNACES

Regardless of the size of the vacuum-induction melting furnace, the basic requirements are essentially identical and fall into the following categories:

(*a*) Melting furnace and power supply
(*b*) Ingot mould and hearth
(*c*) Tank
(*d*) Vacuum system
(*e*) Auxiliary apparatus.

The 2 200-lb furnace at Utica, in basic operating principle and requirements, is no different from the 15-lb laboratory furnace.

Melting furnace and power supply

High-frequency induction heating is ideally suited to vacuum-melting operations because the rate of melting and the temperature of the melt are easily controlled. In general, the induction furnace assembly is similar in design to its air-melting counterpart, except that the coil voltage rarely exceeds 400 V. The voltage is kept low to prevent corona and arcing, which tend to occur in vacuum at pressures in the range 10–500 μ on uninsulated coils. As furnace sizes become larger, however, the need for higher melting power raises the coil currents to such values that at 400 V the conductor size becomes very unwieldy. The 5 000-lb furnace at Utica is designed for 800 V and a melting power of 1 100 kW. It was built by ASEA in Västerås, Sweden, who also furnished the tanks and auxiliary equipment. Figure 1 shows the induction-furnace coil assembly before installation in the furnace tank. The induction coil is surrounded by vertical magnetic yokes, which press radially on the coil to give it rigid support. The yokes also provide a path for the magnetic flux outside the charge to permit the use of magnetic material in close proximity to the coil without danger of overheating. The power-supply system for these large furnaces must be selected with great care. For a 5 000-lb furnace with a crucible of 25 in. i.d., the optimum frequency for most efficient heating is about 900 c/s. It is extremely

* U.S. Patent No. 2 809 110

important that vigorous stirring of the melt be obtained so that reactions at the melt/vacuum interface can proceed rapidly. The inductive stirring afforded by 900 c/s is not sufficient to bring about satisfactory movement of the melt without raising the temperature excessively. The ideal situation is one in which the rate of stirring can be varied independently of the rate of heating, thereby allowing the temperature of the melt to remain at a fixed value and stirring to proceed at whatever rate is determined to be most effective. This result was obtained in both the 2 200- and 5 000-lb furnaces by the use of the dual-frequency system developed by ASEA in Västerås, Sweden. In addition to the 1 100 kW of 900-c/s power available for heating, low-frequency generators supply up to 800 kVA of 30-c/s power to bring about stirring. This low frequency is applied independently to the same coil used for heating. Sixty seconds is sufficient time to mix an addition of 3%Al and 3%Ti completely in a 2 200-lb charge. The time required for degasification has also been effectively reduced by this closely controlled stirring technique.

The problem of ceramics for the crucible is one that leaves much to be desired so far as lining life is concerned. The refractory at present most widely used for vacuum-induction melting contains 70% magnesia and 30% alumina. In small furnaces up to 300 lb, crucible lives of 50 or more heats are obtained with no difficulty. As the furnace size increases, the number of heats that can be made before a lining must be replaced decreases considerably. Much work is being done on this problem by refractory manufacturers as well as vacuum melters, and the final answers will lie not only in the selection of the proper ceramic combination but also in the size distribution, the method of ramming, and the means of firing the unsintered lining.

Ingot moulds and hearth

The moulds in which the ingots are cast are very similar to those used in conventional melting shops, and the mode of hot topping varies from refractory-lined hot tops through exothermic linings to the use of electric-arc hot topping. The field of ingot casting still needs exploration to take advantage of one of the secondary features of vacuum melting, the ability to vary the pouring rate through wide limits with no possibility of contamination from the surrounding atmosphere. Indications point toward advantages that may be gained under certain conditions by very slow pouring rates. This can be accomplished with little difficulty in the vacuum chamber.

Another important area of the vacuum furnace is the hearth on which the moulds are placed. In many early furnaces little attention was given to the need for sufficient space to enclose the variety of ingot moulds that are needed in production operations. Later furnaces were improved considerably. Some included tunnel-like chambers with vacuum locks so that a procession of ingot moulds could be moved into position, poured, and removed without breaking vacuum in the tank. The 5 000-lb furnace has a mould chamber completely separate from the melt chamber (Fig. 2). This chamber has an 8-ft dia. turntable to accommodate a wide variety of moulds and to index them into pouring position. If it is desired not to move the mould after pouring, a movable tundish is used, which directs the stream of metal into successive moulds. This mould chamber can be blanked off from the melting chamber; it has its own vacuum system permitting long-time solidification under vacuum or the installation of new moulds while a new charge is being placed in the melting chamber. The moulds are brought into position by means of a hydraulic ram, which raises the entire mould table and bottom cover into position.

Tanks

The tank required to house the melt, crucible, moulds, and associated equipment varies with furnace size and application. Small furnaces were easily enclosed in a vertical tank with a removable top cover. As furnaces grew larger and were designed especially for production applications, the vertical tank proved difficult to service between melts; most modern furnaces larger than 300 lb are enclosed in horizontal tanks, which give much better access to the inner parts. The tank for a 2 000-lb furnace approaches 12 ft in diameter; larger furnaces require tanks of even greater size. In designing the 5 000-lb furnace at Utica, a radical departure from the horizontal tank was made; the top of the mould chamber is on the left and the melting chamber on the right (*see* Fig. 3). These two tanks are completely separated by the vacuum valve so that independent operations can proceed. Because of the magnetic yoke structure surrounding the induction coil, the tank enclosing the melting chamber can be made from low-alloy steel and fits rather closely around the furnace coil assembly.

Vacuum system

There are several sources of gas which must be handled by the pumping system:

(1) The air present within the tank under standard conditions
(2) The air occluded in tank walls, refractory, etc.
(3) Dissolved gases in the charge
(4) Gases resulting from reduction of oxides under vacuum
(5) Air leakage into the furnace from outside.

The vacuum pumping system must be designed to handle these various gas loads over a wide range of pressures. Two basic types of pump are required. Mechanical pumps provide the pumping capacity from atmospheric pressure down to about 200 μ; below this pressure they lose their efficiency rapidly. Oil-diffusion pumps with their jets designed to give highest speed from 1 to 200 μ are used to handle gas loads at these reduced pressures. These pumps remove the gases from the chamber and compress them to a pressure such that they can be pumped to atmosphere by the mechanical pumps. Many different diffusion pumps are now available in a wide range of sizes. It is possible to obtain a single pump to handle all the gas loads from a 2 000-lb furnace. A slightly different approach was used, however, on the 5 000-lb furnace at Utica. Instead of one or two pumps of a large size, a multiple of small sizes were connected to a 4-ft dia. manifold. Despite the fact that the area of the manifold is smaller than the total throat area of the pumps, little difference was observed between the theoretical pumping speed and the measured pumping speed within the melting chamber. In case of pump

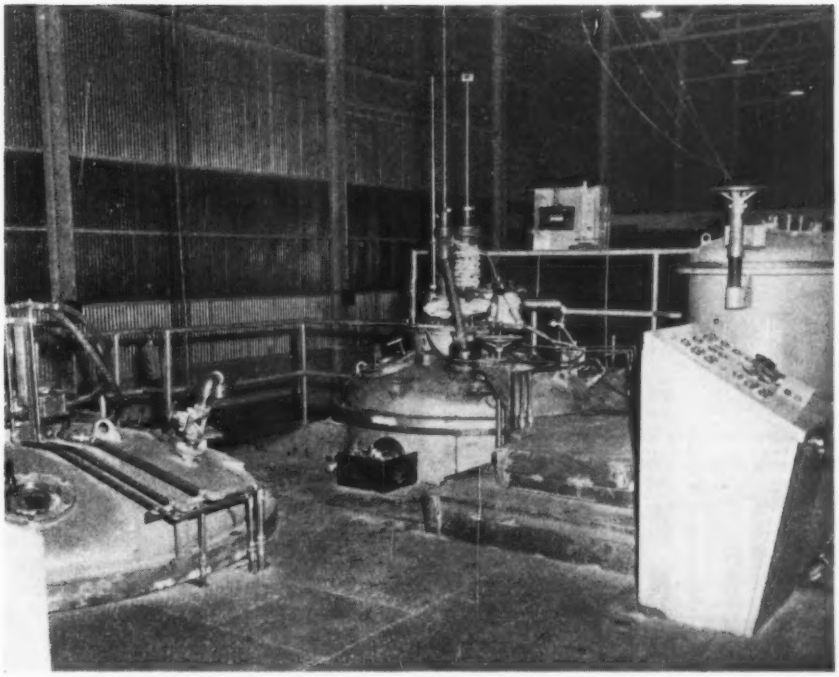

Fig. 3—Operating platform of 5 000-lb furnace showing cover of melting chamber at right and upper cover of mould chamber at left. At extreme right can be seen the addition-making device

failure, the offending pump may be isolated quickly without impairing the overall pumping capacity too severely. Figure 4 shows the 5 000-lb furnace pumping system, which consists of twelve 16-in. diffusion pumps backed up by four Roots-type blowers and mechanical pumps. This pumping capacity is sufficient to evacuate the chambers to 10 μ in 7 min and to handle the gas removed from the molten metal with a pressure rise in the melt chamber of not more than 10 μ. Before pouring, the entire chamber is pumped to a pressure of approximately 1 μ.

Auxiliary apparatus

Auxiliary apparatus includes such items as addition-making devices, samplers, temperature-measuring devices, control systems, etc. A very important feature in many vacuum furnaces is the additions maker, which allows material to be added to the crucible in controlled quantities at any time during the melting cycle. There are two main approaches to this problem: (*a*) a system of cups within the furnace whose contents can be dumped into a chute, and (*b*) a vacuum-locked chamber to hold the material to be added to the melt. The 5 000-lb furnace has a vacuum-lock mechanism which can be loaded with 2 400 lb of metal in twelve compartments. The contents of each compartment can be introduced into the crucible by means of a screw feeder at any desired rate. This arrangement makes it possible to charge the crucible and make subsequent additions without bleeding the chamber to atmosphere. Small quantities of a few pounds or less can be added through a vacuum lock above the crucible at any time.

To be certain that the chemical analysis of the final melt is within specification, samples are dipped from the crucible, withdrawn through vacuum locks, and analysed spectrographically. For proper control of temperature, both a disappearing-filament optical pyrometer and high-temperature dipstick thermocouples are used. The optical pyrometer is sighted on the surface of the bath through a window in a long narrow tube.

Complete reliability of all components is necessary to operate large-scale vacuum furnaces successfully on a production basis. Unlike conventional air-melting operations, where access can be had to practically all moving parts at any time, in vacuum operations the melting furnace, tundishes, moulds, and addition makers are isolated in a tank and must be operated by remotely controlled manipulators. Mechanical failure may require the opening of the furnace for repair, which means freezing the melt, an expensive loss of time, and perhaps a scrapped heat. While the tendency in new designs is always toward more complicated equipment and instrumentation, the best assurance of trouble-free operation is to use the simplest mechanisms possible.

A strict preventive maintenance programme is also important. Vacuum seals, bearings, valves, and electrical contacts must be inspected and cleaned at frequent intervals, in some cases after each heat. Dust deposits of evaporated metal, which collect on all cool surfaces within the melting chamber, are particularly detrimental and must be removed from rotating or sliding surfaces.

Despite the excellence of furnace design, it would

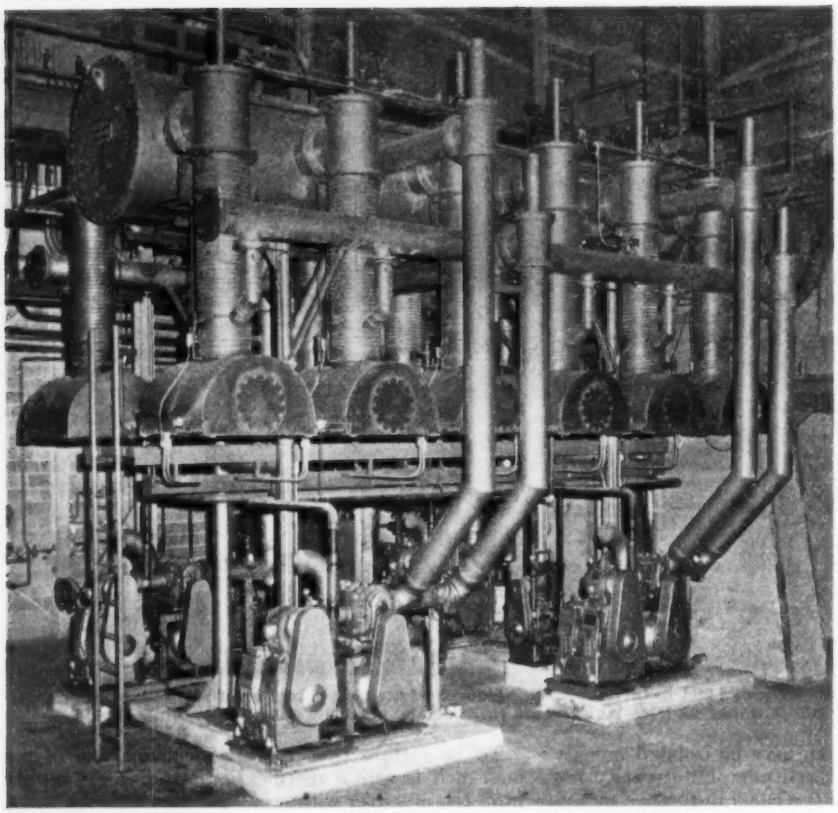

Fig. 4—Pumping system for 5000-lb furnace

be difficult to make consistent heats on a production basis without well trained operators. At Utica, operators are given a year's training, during which they learn not only the mechanics of furnace operation, but also enough of the metallurgy involved to give them a full appreciation of the reasons for strict adherence to established melting practices. Such men must be relied upon to maintain the same degree of control on 5 000-lb heats as on laboratory melts.

PRINCIPLES OF VACUUM-INDUCTION MELTING

The question might be raised at this point as to the reasons for vacuum-induction melting. The equipment described might be very interesting and ingenious, but the question should be answered : ' What are the metallurgical reasons making it worthwhile to construct such elaborate equipment ? ', and a stock-taking at this point is essential.

Probably the most important metallurgical justification for vacuum-induction melting is that of all known methods it provides the greatest degree of control over composition. The term ' composition ' is meant to include not only the desired alloy additions but impurities as well. This control is achieved through the following capabilities:

(1) To isolate the melt so that it can be treated as a system in the thermodynamic sense. Vacuum-induction melting does this by preventing gases from outside the system from contaminating gases in the system
(2) To control the pressure within the system
(3) To stir the melt
(4) To allow time for refining reactions to go to completion.

The advantages of vacuum-induction melting accrue from these capabilities. In the simplest case, the melt is prevented from coming in contact with oxygen and nitrogen from the outside. Because of the lower pressure, reactions can now take place or can be carried to completion faster than they would at atmospheric pressure. On the other hand, by melting under pressure, i.e. by melting under a gas at pressures higher than atmospheric, it is possible to carry out reactions that again are not possible at atmospheric pressures. Inductive stirring plays two important roles. It homogenizes the melt composition, and it brings reactants to the melt/vacuum interface where the reaction can proceed rapidly to completion. The final capability of allowing time for the reaction to proceed is extremely important and has not been sufficiently appreciated in the past. It would be interesting here to consider some of these aspects of vacuum-induction refining in greater detail.

The most important deoxidation reaction in vacuum-induction melting is the reaction $C + O = CO$. The effect of pressure on the equilibrium carbon–oxygen product is marked. For example, the theoretical equilibrium concentration of oxygen in a 1%C steel at 1 600° C varies from 0·005% at 1 atm of CO pressure to 6×10^{-8}% at 0·01 mm of CO pressure. The latter pressure is easy to obtain in vacuum-

induction melting systems. Although this low level of oxygen has not yet been reached (the limitation is not a thermodynamic one), there is no reason to believe that the oxygen levels at present achieved are the minimum possible. This type of reaction can be used also to get rid of other elements, provided that they form volatile products. Such a reaction is desulphurization in nickel-bearing alloys. This reaction is shown in Fig. 5, which also illustrates another of the capabilities of vacuum-induction melting, the ability to allow time for refining to occur. As shown, about 60 min are required in a 6-lb melt to reduce the sulphur in 80–20 Ni–Co alloy from 0·03% to 0·005%.

Deoxidation proceeds in two steps: by boiling and by the elimination of CO at the melt-vacuum interface. It is believed that the latter step is rate-limited by the diffusion of C or O through the melt adjacent to the interface towards the interface. At sufficiently low values of the oxygen content it is believed that the melt reduces the refractory oxide comprising the crucible. Under these circumstances, oxygen is both supplied to and discharged from the melt. Moore[2] suggested this process to account for his observations of a minimum oxygen content as a function of time in low-carbon iron.

Machlin[3] has recently considered the kinetics of deoxidation theoretically and has made certain predictions based on a model of the rate-limiting steps in deoxidation. According to this model, boiling, which is heterogeneously nucleated, ceases when the partial pressure of the boiling vapour at the nucleating site becomes less than the sum of the metal head and the pressure in the tank. Thus, boiling ceases to occur first at the bottom of the melt. Cessation of boiling is experimentally rapid, which implies that the boundary between active and non-active nucleating sites passes upwards rapidly to the top of the melt. During deoxidation, boiling accounts for the major loss of oxygen from the melt. The second stage of deoxidation is, however, equally important because it is just the remaining oxygen content that often comprises the major difference between what can be achieved by the present and by other vacuum-melting processes. During the second stage, induction stirring continually brings the melt to the melt/vacuum interface. According to Machlin's model, the impurities are discharged by diffusion through the moving layer of melt adjacent to the interface into the vacuum, provided that they are also continually removed by the pumps or other traps. This process takes time. Time is allowed for this stage of refining in vacuum-induction melting, but it is absent in other vacuum-melting processes. The importance of this stage of vacuum-induction melting is illustrated by the following example. Recently the rate of removal of oxygen from a low-carbon iron in this stage has been measured at Utica. About 30 min are required to reduce the oxygen content from about 200 to 20 p p m. It is expected that slower-diffusing impurities would require longer refining periods.

One of the most important contributions of Machlin's work is the prediction that the carbon–oxygen product of vacuum-induction-melted steels is not a thermodynamic parameter but rather a kinetic parameter. This prediction stems from Moore's suggestion

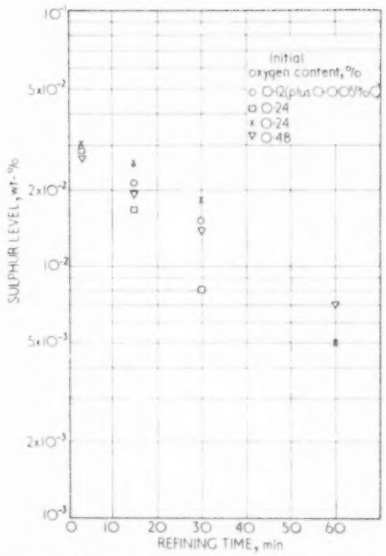

Fig. 5—Desulphurization of an 80–20 Ni–Co alloy in vacuum

that the crucible is a source of oxygen and that when the oxygen content of the melt becomes sufficiently low the crucible itself contributes oxygen to the melt. At any given carbon level it is believed that a steady-state oxygen concentration is reached that corresponds to the value at which the rate of deoxidation equals the rate of oxidation (oxygen provided by the crucible). The carbon steady-state oxygen product predicted by Machlin is not a constant (even taking activities into account). Rather, it is predicted that above a certain carbon content the oxygen concentration approaches a constant value which is determined by the crucible, the bath size, and the diffusivities in the melt of oxygen and the metal component of the crucible refractory. A comparison between this prediction and the experimental values for pure iron containing carbon and oxygen obtained by P. Turillon in our laboratories is given in Fig. 6. The minimum values of oxygen are believed to correspond to the steady-state values. As shown, the minimum values of oxygen content do appear to approach a constant value at high carbon contents, as predicted by Machlin. For comparison, the calculated equilibrium curves for CO pressures of 76 and 2·9 mm Hg based on Chipman's thermodynamic data[4] are shown dotted. The curve corresponding to the carbon–oxygen equilibrium at 0·01 mm Hg pressure lies several orders of magnitude below the bottom dotted curve.

The fact that the equilibrium curve corresponding to a pressure of about 3 mm Hg of CO approximates a minimum line through the points at low carbon contents has led Samarin[5] to conclude that there is little reason to melt *in vacua* below 3 mm Hg. In fact, this conclusion is further justified by Samarin on the basis that the head of melt inherently limits the minimum CO pressure that can be achieved in equilibrium with the melt. The critical experiments to distinguish between these viewpoints remain to be

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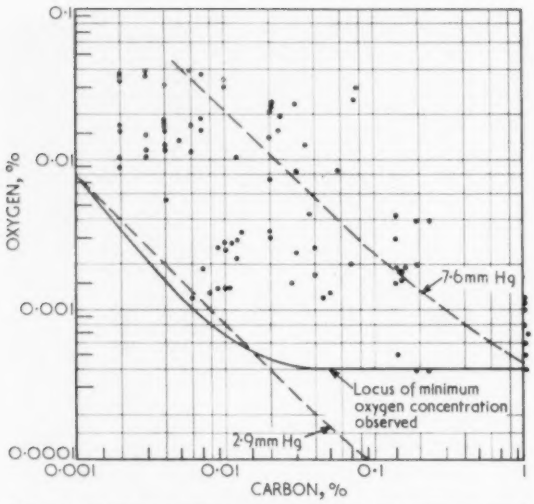


Fig. 6—Carbon–oxygen contents of vacuum-melted pure iron melted in magnorite crucibles

conducted. We believe, however, that kinetic factors probably limit the minimum oxygen content. Operating according to this belief we hope to be able to produce large melts of high-purity iron for the electrical industry containing less than 5 ppm each of carbon and oxygen in the near future. It is already possible with small melts and fused MgO crucibles to produce iron containing less than 20 ppm each of carbon and oxygen.[6]

The divergence between this type of melting and air melting becomes apparent, and it should be obvious why certain elements, such as manganese and silicon, that are classified as deoxidizers in air actually do not act as such in vacuum-induction melting. For example, an actively boiling melt under a vacuum of 10μ will continue to boil even though silicon is added to it; however, aluminium will kill the melt. Alumina is not easily reduced, although in nickel-based alloys it may be reduced at a pressure of 10μ on long holding at fairly high temperatures of about 1 500° C. This will also explain why in properly made vacuum-induction melts there will be no silicate inclusions. On the other hand, it can also be seen why it is very easy to make an extremely dirty heat of vacuum-induction-melted material. If the refining is not carried out properly (e.g. aluminium is added just after boiling ceases and the melt is poured immediately), an extremely dirty ingot will result, since these ingots are fairly small and not much time is available for floating out oxides. Vacuum-induction melting is thus not a panacea but is a more controllable method of melting. The quality of the product depends upon the intelligent use of the refining control inherent in the method.

Another refining reaction that can be carried out in vacuum-induction melting is the volatilization of low-melting-point materials such as lead, arsenic, and bismuth. Although few data are available, the importance of this type of reaction should not be underrated. It may be that some of the great improvement in properties, which will be discussed later, of vacuum-melted materials may be due in great part to the volatilization of minute quantities of these materials. This problem is magnified by the fact that chemical and analytical methods are in most cases not advanced enough to permit quantitative determination of these effects; however, work is in progress in our laboratory that may throw some light on this problem.

Another great advantage that accrues in this type of melting is the ability to maintain accurate control of the chemical composition. A heat can be duplicated over and over again to extremely close specification ranges; however, since quite a few of the normal alloying elements, such as chromium and manganese, volatilize rapidly *in vacuo*, the melting practice must be closely controlled and compensation made for the volatilization of these elements.

APPLICATIONS OF VACUUM-INDUCTION MELTING

In the previous section, the advantages of vacuum-induction melting were discussed. With these advantages it is possible to produce certain products, which fall into certain natural groupings:

(1) Alloys that contain reactive elements
(2) ' Cleanliness ' metals and alloys
(3) Alloys requiring exceptionally close control of composition.

Alloys that contain reactive elements

Vacuum-induction melting has been found at Utica to be advantageous in producing alloys containing the reactive elements Al, Ti, B, Ce, Nb, Ta, Zr, W, and Mo. For example, the first two elements (aluminium and titanium) are contained in nearly all the nickel-based age-hardening high-temperature alloys. The improvements in the stress-rupture properties of Waspaloy by vacuum-induction melting can be demonstrated by a comparison of the air-melting specification for this material in 1952 and the present vacuum-melting specification, as shown in Figs. 7*a*, *b*, and *c*. Vacuum-induction melting has made it possible to increase both titanium and aluminium contents in nickel-based alloys and thereby achieve the high-temperature strengthening associated with these precipitation-hardening elements. Although these increases in strength are phenomenal and are to a large extent responsible for the power output and operating temperature of modern aircraft gas turbines, vacuum-induction melting appears to

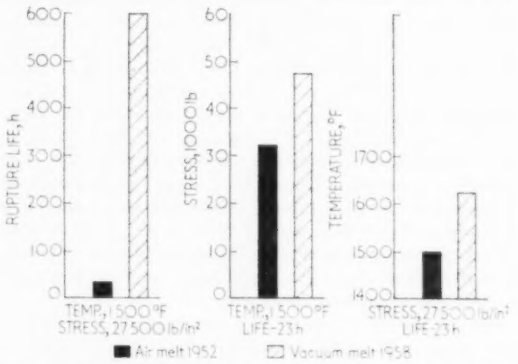
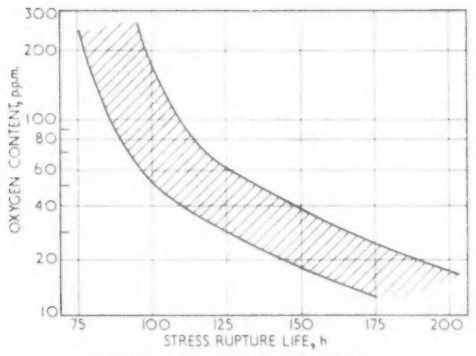


Fig. 7—Waspaloy specification for air-melted material in 1952 compared with latest vacuum-melted specifications in 1958



Nickel-base alloy, 1 600°F at 25 000 lb/in²

Fig. 8—Effect of final oxygen content on stress-rupture properties of nickel-based high-temperature alloys

confer an additional advantage not associated with increases in the amount of precipitation-hardening elements. Jones[7] has reported a correlation between rupture life of a nickel-based alloy and the oxygen content of the alloy *in trace amounts*; this correlation is reproduced in Fig. 8. According to this curve, as the oxygen content is decreased below about 40 p p m there is a marked increase in rupture life. The basis for this correlation is still not understood. However, work in progress in our laboratory confirms to some extent the existence of this relation. If the rupture life does depend upon the oxygen content in trace amounts, there is little doubt that further improvements in the high-temperature rupture strength of these alloys will be achieved in the near future.

Not only is the high-temperature strength of alloys containing reactive metals sensitive to oxygen, but the workability, the ductility, the transition temperature between ductile and brittle behaviour, and the electrical and magnetic properties are similarly sensitive, not only to oxygen but also to other imperfection and interface active elements (nitrogen, carbon, etc.) as well. Not all these interface active elements are harmful; boron, in particular, is extremely beneficial to the mechanical properties, in trace amounts. It has long been known that boron has similar effects in air-melted alloys; however, it is much easier to control this effect of boron in vacuum-induction-melted alloys because oxygen, which combines strongly with boron, is removed from the tank and melt before the addition of the boron. Freeman *et al.*,[8] Koffler *et al.*,[9] and the present authors have studied the effect of boron on the

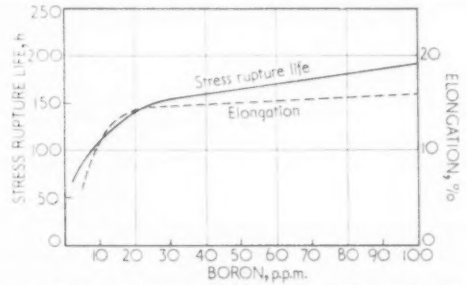


Fig. 9—Effect of boron on the ductility and stress-rupture life of Waspaloy

TABLE I
Comparison of air-melted and vacuum-melted nickel-aluminium-bronze alloy

	Air-melted	Vacuum-melted
Tensile strength, lb/in²	90 000–115 000 (heat-treated)	120 000–123 500 (heat-treated)
0·2% yield strength, lb/in²	40 000–70 000	86 200–90 000
0·02% yield strength, lb/in²	...	72 000–78 000
Reduction in area, %	5–15	9·4–12·4
Brinell hardness	172–300	255
Brazeability	Poor	Excellent

properties of nickel-based alloys. The remarkable effect of trace amounts of boron on the rupture life of Waspaloy, a nickel-based alloy, is illustrated by data obtained in our laboratories in Fig. 9; only 15 p p m is sufficient to double the rupture life. It has been necessary, therefore, to control the boron content within very narrow limits to obtain consistent rupture results. Normal production heats are now controlled to within $\pm$ 5 p p m boron.

Another example of a reactive-metal-containing alloy that has been melted at Utica is nickel–aluminium bronze. Some remarkable increases in properties have been obtained, as shown by Table I. Perhaps the most interesting result is that the vacuum-induction-melted bronze is brazeable whereas the air-melted bronze is not.

The exploitation of this advantage of vacuum-induction melting (i.e. the melting of reactive-metal-containing alloys) is still in its infancy. It is safe to predict that a host of new alloys with unusual properties will be produced by this melting technique in the next ten years.

' Cleanliness ' alloys

Another group of alloys produced by vacuum-induction melting is based upon both the elimination of the atmosphere and the control of pressure; this group may be called the ' cleanliness ' alloys. Foremost in the group is 52100; in this alloy the primary effect of vacuum-induction melting is to reduce the population of oxide inclusions. The sulphide inclusions in manganese-containing 52100 are unaffected by vacuum-induction melting. There is no gaseous sulphide known that has a sufficiently high free energy of formation to be able to vacuum-refine sulphur from iron, although it is possible to do this in nickel-based alloys. There are many techniques available, however, for refining the sulphur from the iron which do take advantage of vacuum-induction melting, e.g. the use of vacuum-induction melting to remove oxygen, followed by the combination of the sulphur with cerium. None of these techniques has yet been developed to production scale. The most promising from a commercial viewpoint is simply to remove the manganese from 52100, since it is believed that manganese is not needed in vacuum-induction-melted 52100 because the actual sulphur content in the raw material is much below the solid solubility of sulphur in manganese-free 52100. This vacuum grade of 52100 has the advantage of being the cleanest (most inclusion-free) grade for the lowest cost.

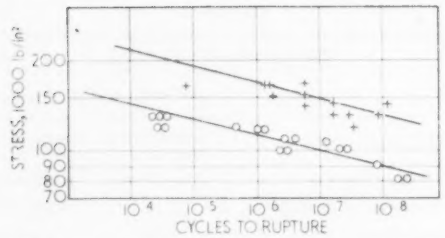


Fig. 10—Improvements of fatigue properties for vacuum-melted 52100 steels

Concomitant effects of vacuum-induction melting 52100 and other alloys steels are a marked increase in fatigue strength and a decrease in the impact transition temperature. Until recently, most of our productive capacity was required to produce high-temperature alloys, and it has only been since the installation of new equipment that it has been possible to any great extent to produce vacuum-melted steels. Consequently, our data on improvements to be gained from vacuum-melting ferrous alloys are rather limited. In order to give a complete picture of the benefits to be gained by this process, data from other vacuum-melting companies are presented below.

Moore[2] demonstrated a marked improvement on the fatigue behaviour of vacuum-melted 52100 over the commercial product. The results are shown in Fig. 10. He also found " a small but definite difference in impact behaviour . . . ," illustrated in Fig. 11, where a reduction in the impact transition temperature from 200° to 100° F is demonstrated.

While the true reasons for the improvement in properties of this material are still a matter of conjecture, the benefits realized in the final product are nevertheless real and impressive. Cobb,[11] in a report on the testing of commercial 52100 bearings compared with similar products made by vacuum melting, shows a marked increase in bearing life using the latter material (*see* Fig. 12.)

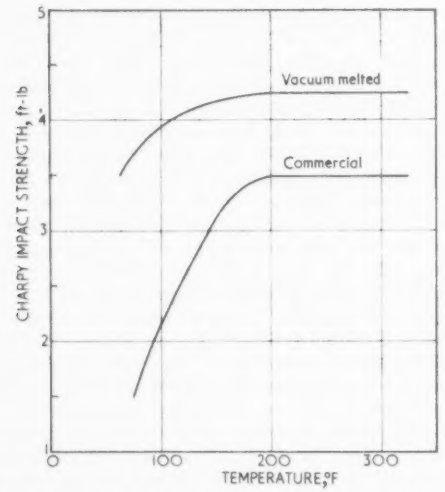


Fig. 11—Effect of vacuum melting on impact transition temperature for 52100

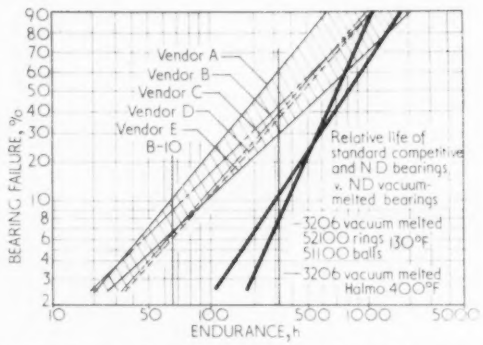


Fig. 12—Comparison of bearing life of several commercial air-melted bearings with vacuum-melted bearing materials

Another high-strength steel, 4340, has been improved both in impact strength and tensile ducility, particularly in the transverse direction. These results, discussed by Aksoy,[10] are shown in Figs. 13 and 14.

Close composition control

The degree of control that can be achieved in vacuum-induction melting is illustrated in Fig. 15. The deviation in analysis from heat to heat is less than the error inherent in the analysis itself. Alloys sensitive to compositional variation can thus be advantageously produced by vacuum-induction melting. One such alloy is the heat-treatable balanced austenitic stainless steel. We are investigating the production of this alloy using yet another control feature, the ability to introduce controlled amounts of nitrogen by controlling the partial pressure of nitrogen above the alloy. Other alloys that may fall into this class are those for magnetic applications, where small variations in nickel content vary magnetic properties by undesired amounts.

ECONOMICS

This subject has been discussed at length by Darmara.[12] The main point of his argument is that a fair comparison between air and vacuum melting cannot be determined on the basis of cost of the melting operation alone, but that technical considerations such as specifications to be met must be considered. There is no question that vacuum-induction melting is an expensive melting operation. The equipment is

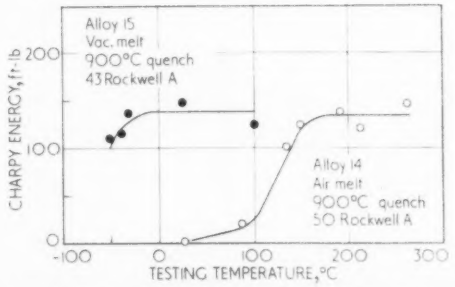


Fig. 13—Effect of vacuum-induction melting on transition temperature of 4340 steels

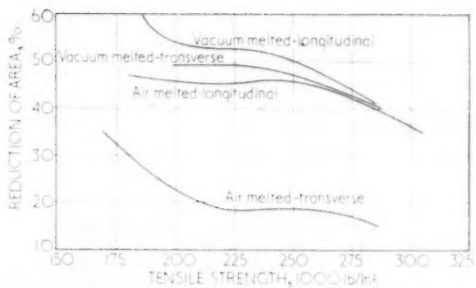


Fig. 14—Comparison of tensile ductility of vacuum- and air-melted 4340 steels

complicated and the capital expenditure per pound produced is much higher than with standard facilities. Furthermore, maintaining equipment of this nature in peak running condition requires trained and skilled maintenance personnel. The key to successful continuous production depends on the efficiency of the maintenance set-up and the existence of a realistic preventive maintenance programme. These costs are, of course, reflected in the cost of the final product. However, these high costs are partly compensated by a decrease in total scrap, so that in practice a more saleable product results from a given melt weight. This ratio, which is the recovery, obviously depends upon the severity of buyer's specifications.

The following analysis, which is still valid, is taken from a paper by two of the present authors.[13] The analysis is based on Waspaloy, a high-temperature alloy in use in the USA. The base price of this alloy air-melted is about \$6.00, while that of the vacuum-induction-melted alloy is about \$7.00. Figure 16 shows the mortality of heats air-melted and vacuum-melted.

If the purchase specification for stress-rupture is set at 90 h and an attempt is made to meet this with air-melted material, the rejections of heats would amount to 50%. At about 100 h almost 75% of all heats would have to be scrapped and, in order to meet

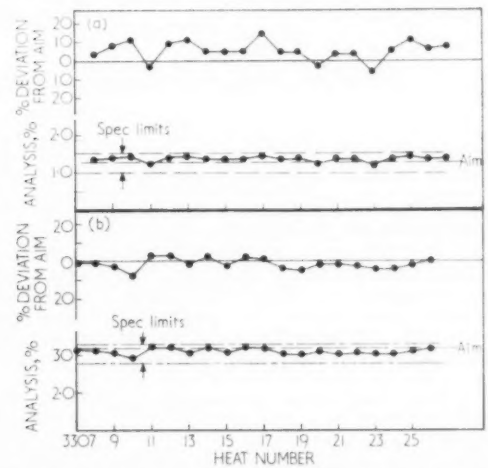


Fig. 15—Reproducibility in the achievement of composition control in consecutive heats: (*a*) aluminium in Waspaloy; (*b*) titanium in Waspaloy

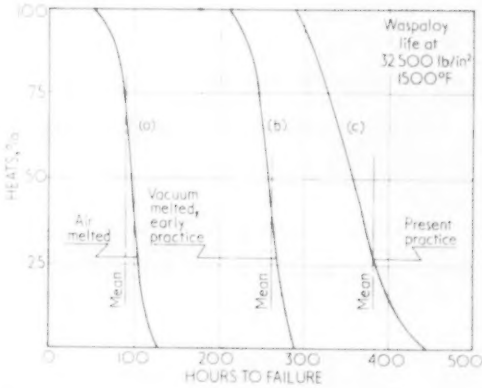


Fig. 16—Comparison of mortality of (*a*) air-melted Waspaloy; (*b*) early vacuum-melted Waspaloy; (*c*) present vacuum-melted Waspaloy

his costs, the manufacturer would have to triple his selling price. On the other hand, vacuum-induction-melted material easily meets a specification of 300 h.

It is seen, therefore, that vacuum-induction-melted material is economically advantageous for materials purchased to rigid specifications, and that some of these specifications can be met only by vacuum-melted materials.

Acknowledgment

Acknowledgment is made to the following workers whose results have been reproduced in the figures indicated: W. E. Jones, Metallurgical Products Department, General Electric Co. (Fig. 8); J. H. Moore, Metallurgical Department, National Research Corp. (Figs. 10, 11); L. D. Cobb, New Departure Division, General Motors Corp. (Fig. 12); A. M. Aksoy, Vacuum Metals Corp. Syracuse, N.Y. (Figs. 13, 14).

References

1. W. E. Britton *et al.*: "Vacuum melting": report to Professor G. F. Doriot, Harvard Business School, April, 1957.
2. J. H. Moore: *Met. Prog.*, 1953, vol. 64, Oct., pp. 103–105.
3. E. S. Machlin: Paper submitted to AIME.
4. J. Chipman: "Basic Open Hearth Steelmaking," ch. 16, p. 671: 1951, New York, AIME.
5. A. M. Samarin: "Deoxidation of steel in vacuum," New York University Vacuum Metallurgy Course, June, 1957 (to be published).
6. W. A. Fischer and A. Hoffman: *Arch. Eisenhütt.*, 1958, vol. 29, p. 339.
7. W. E. Jones: "Induction melting of ingot products," New York University Vacuum Metallurgy Course, April, 1957 (to be published).
8. R. F. Decker, J. P. Rowe, and J. W. Freeman: University of Michigan, Report No. 55 of the Engineering Institute to NACA, January, 1957.
9. R. W. Koffler, W. J. Pennington, and F. M. Richmond: Universal-Cyclops Steel Corporation, Research and Development Report No. 48 to NACA, June, 1958.
10. A. M. Aksoy: Private communication.
11. L. B. Cobb: Private communication.
12. F. N. Darmara: Vacuum Melting Symposium, Investment Casting Institute, Detroit, Mich., 1956.
13. F. N. Darmara and J. S. Huntington: *ASME* Paper No. 55–A–198, November, 1955.

Correspondence on the paper

The electrical resistivity of high-purity iron–carbon alloys*

By S. V. Radcliffe and E. C. Rollason

Mr **J. Barford** and Mr **J. S. White** (University of Liverpool) wrote: As stated in the paper, certain physical properties of mixtures can be calculated from the property of each of the components by use of the equation:

$$\epsilon^k = \Sigma_i \theta_i \epsilon_i^k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where the volume fraction of the ith constituent is θ_i, the physical property is ϵ_i, and the resultant property of the mixture is ϵ. The value of the index k is restricted to the range $-1 < k < +1$, depending on the form and dispersion of the constituents. To justify theoretically the use of a semi-log plot relating resistivity to the volume percentage of cementite, k must be constant, or reasonably so, over the composition range studied and its value must be such that $-\frac{1}{2} < k < +\frac{1}{2}$. Only by making these assumptions is it possible to derive the relationship

$$\ln \epsilon = \Sigma_i \theta_i \ln \epsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

It seems that the authors have applied equation (2) to a set of observations that do not comply with these limiting conditions. This can be shown by using their values for ρ cementite and ρ ferrite to calculate the value of k for each of their results. As shown in Fig. *A*, 40% of the k values are greater than $+\frac{1}{2}$, and for alloys containing less than 2 vol-% of cementite the value of k is greater than 1. This latter result is impossible, and so it must be concluded that the value of ρ cementite deduced from the authors semi-log plot (Fig. 4) is seriously in error.

The experimental resistivity data is of a high order of precision. In view of this it is unwarranted to weigh certain points arbitarily by using a semi-logarithmic plot. Even so, the point representing the eutectic alloy does not lie on the line and so has no influence on the value of ρ cementite deduced. It is suggested that the relationship between resistivity and carbon content is better represented by a smooth curve passing through all the points. This suggestion is supported by recent results which we have obtained with high-purity Fe–Mn–C alloys. The resistivities plotted as a function of carbon content, for a constant manganese series, lie on a smooth curve. Compared with the results obtained by Radcliffe and Rollason, the curvature at low carbon contents is accentuated and made more apparent, presumably owing to the effect of manganese.

The discrepancy between the value of the resistivity of pure iron obtained by the authors and the values reported by other investigators is attributed to the presence of 0·005%C retained in solution in α-iron. The discrepancy can be explained in a less sophisticated way. It appears from the paper that Radcliffe and Rollason's result refers to 24°C, whilst Pallister and the National Bureau of Standards quote their values for 20° C. From Pallister's results we have calculated the coefficient of resistivity for pure iron to be 0·054 $\mu\Omega$-cm/°C. Thus, correcting the authors' result to 20° C gives a value of 9·70 $\mu\Omega$-cm, the values obtained by the National Bureau of Standards and Pallister being 9·71 and 9·81 $\mu\Omega$-cm respectively.

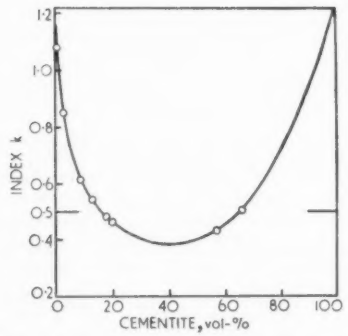


Fig. A—Index k as a function of carbon content calculated from equation (1) using the authors' experimental data ($\rho_{Fe_3C} = 79 \cdot 5\ \mu\Omega$-cm)

AUTHORS' REPLY

Dr **S. V. Radcliffe** (MIT) and Professor **E. C. Rollason** (University of Birmingham) wrote: It is interesting to note that Barford and White have been using Radcliffe's original apparatus for tests on Fe–Mn–C alloys and that they raise two criticisms of our paper, both of which are invalid. The suggestion in their last sentence completely misses the point, in that the extrapolated value of the resistivity of pure iron with which the measured value agrees so well is only given to promote confidence in the extrapolation of the same line to give the value of the iron carbide. Further, we state in Table I that resistivities were preserved at 24°C.

Their main argument seems to be invalid owing to a slip in their mathematics.

In expanding equation (1)

$$\epsilon^k = \Sigma_i \theta_i \epsilon_i^k$$

logarithmically, they have assumed that if $A = B + C$ then

$$\ln A = \ln B + \ln C$$

whereas correctly,

$$\ln A = \ln (B + C)$$

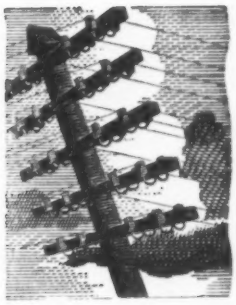
It was precisely because of this difficulty of direct logarithmic expansion that our initial assumption that $+\frac{1}{2} > k > -\frac{1}{2}$ was made. On inserting our results in the resulting equation (2) of the resistivity paper we obtained a good straight line — which is surely indicative that the equation is applicable. As to the assumption that $+\frac{1}{2} > k > -\frac{1}{2}$, inserting our values for ρ_{Fe} and ρ_{Fe_3C} into equation (1) gives values for k of slightly less than $+0 \cdot 25$ for all values of θ from 0·05 to 0·95, i.e. 5–95 vol-% Fe_3C, well within the required range for k. The Barford and White suggested value of $\rho_{Fe_3C} = 190$ thus is quite unacceptable.

The comment on the impossibility of the results fitting both linear and logarithmic plots might be valid if we had plotted the same data in both plots; in fact we plotted ρ/wt-%C and log ρ/vol-% Fe_3C.

* *JISI*, 1958, May, vol. 189, pp. 45–48.

N E W S

Announcements and News of Science and Industry



THE IRON AND STEEL INSTITUTE

Annual General Meeting 1959

The Annual General Meeting of the Institute is being held in London on Wednesday and Thursday, **6th and 7th May.** The technical sessions will include a two-day meeting on recent developments in the application of oxygen to steelmaking, at which papers from Europe, the United Kingdom, and the USA are to be presented and discussed.

The Dinner for Members will be held at Grosvenor House on the evening of Wednesday, 6th May.

Full details of the Meeting will be published in the April *Journal.*

New Special Report

During an investigation into the cause of ingot surface defects and their influence on the product, the Ingot Surface Defects Subcommittee of the British Iron and Steel Research Association became aware that there was a lack of uniformity in the names applied to the defects under review. To reduce the confusion of terms and promote a better understanding of the nature and causes of such defects, the Sub-committee selected those most commonly encountered and assigned to them the most apt term.

The first edition of this survey appeared in 1951 as No. 44 in The Iron and Steel Institute's Special Report Series, and was quickly sold out. In view of the many requests for copies of what is now a standard work of reference, it was decided to issue a second edition, with some important additional material. Through the courtesy of Richard Thomas and Baldwins Ltd., The Steel Company of Wales Ltd., and John Summers and Sons Ltd., the Subcommittee has been able to include an addendum devoted to surface defects in steel strip products.

The second edition is now available as Special Report No. 63, "Surface Defects in Ingots and Their Products"; it consists of 62 quarto pages, illustrated with 134 excellent photographs of surface defects, and bound in cloth with stiff board covers. The Report costs £1 5*s.* 0*d.* (15*s.* 0*d.* to Members); copies may be obtained from the Secretary, The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

NEWS OF MEMBERS

Mr **Arnold Carr** has been appointed chairman of Thomas Smith and Sons (Rodley) Ltd., John Smith (Keighley) Ltd., and the Widnes Foundry and Engineering Co. Ltd.

Mr **W. F. Cartwright** has been appointed a director of Davy and United Engineering Co. Ltd.

Mr **E. W. Colbeck** is now deputy chairman of Hadfields Ltd.

Mr **F. Cousans** has been appointed managing director of Hadfields Foundry and Engineering Ltd.

Mr **D. K. Coutts** has taken charge as managing director of the Nickel Information Bureau recently set up at Melbourne, Australia, by the Inco-Mond Group of Companies.

Dr **W. Davies,** head of the minerals section of the Research and Development Department of the United Steel Companies Ltd., has been additionally appointed geological consultant to the companies.

Mr **G. D. Elliot,** O.B.E., has been appointed to the board of the Appleby-Frodingham Steel Company.

Major **H. G. Freeman** is now deputy chairman of Hadfields Foundry and Engineering Ltd.

Mr **Sven Frisell,** founder managing director of Swedish Iron Ore Ltd. and of Algerian Iron Ore Ltd., has resigned from the boards of both companies on reaching retirement age.

Mr **I. George** has left the Distillers Company Ltd. to become works metallurgist at the Witbank, Transvaal, works of Ferrometals Ltd.

Mr **I. M. D. Halliday** is now in charge of continuous-casting research at the Research and Development Department of the United Steel Companies Ltd.

Dr **J. B. Haworth** is now technical assistant to the Sales Manager of the Freeport Nickel Company, in New York.

Mr **C. Holden** has been appointed head of the furnace research section at the Research and Development Department of the United Steel Companies Ltd.

Mr **A. D. Hopkins** is now Senior Lecturer in Metallurgy at the College of Technology, Birmingham.

Dr **J. E. Hurst,** C.B.E., has been awarded a Company Medal in bronze by the Worshipful Company of Founders.

Mr **E. T. Judge** has been made assistant managing director of Dorman Long (Steel) Ltd.

Mr **A. S. de Muinck Keizer** retired from the position of chairman of the managing directors of Koninklijke Demka Staalfabrieken N.V. on 1st January; he has been appointed a member of the Board of Directors.

Mr **J. N. Kilby** has been made a Fellow of The Institution of Metallurgists.

Mr **S. C. G. Maulik** has joined the Hindusthan Steel Private Ltd., Durgapur Steel Project, as superintendent, steel melting shops.

Dr **J. W. Nordenson** has been appointed Chairman of Swedish Iron Ore Ltd.

Dr **J. G. Pearce,** C.B.E., has been awarded a Company Medal in bronze by the Worshipful Company of Founders.

Mr **T. W. Pease** has been appointed a local director of Hadfields Ltd.

Mr **R. H. Pinder** has joined William Robertson and Co. Ltd. as assistant works manager.

Sir **William Scott,** O.B.E., has been appointed a director of Head Wrightson Teesdale Ltd.

Mr **F. J. Somers** has been appointed chairman of Walter Somers Ltd.

Mr **K. E. A. Sunström** has retired from the position of technical director of Gunnebo Bruks AB.

Dr **P. H. Sykes** has resigned from the board of the British Oxygen Co. Ltd. on taking up an appointment with A. E. Reed and Co.

Mr **G. Wood** has been appointed managing director of Hadfields Forgings Ltd.

It was reported in our December, 1958 and January, 1958, issues that Mr **L. R. Evans** had been appointed a director of the English Steel Spring Corporation Ltd. This information was incorrect; Mr Evans has been appointed a director of the English Steel Castings Corporation Ltd.

Obituary

Dr **Percival Thomas Carter,** B.SC., F.I.M. (*elected* 1945), of Cardross, in a climbing accident.

Mr **Eric Drewery** (*elected* 1937), of Redcar, in February, 1958.

Mr **John Dunbar,** M.I.MECH.E. (*elected* 1951), of Musselburgh.

Mr **Edward William Harpham** (*elected* 1943) of Ebbw Vale, on 1st January, 1959.

Mr **Ernest Wilfred Jackson,** F.R.I.C. (*elected* 1904), of Middlesbrough.

Mr **Hebbalam Srinivasa Sastri,** B.A., B.E. (*elected* 1946), of Rangoon, Burma, on 24th September, 1958.

IRON AND STEEL ENGINEERS GROUP

Meeting in the Netherlands

At the invitation of Mr A. H. Ingen-Housz (Past President), who was until his recent retirement President of the Royal Netherlands Blast Furnaces and Steelworks Ltd., the Iron and Steel Engineers Group is holding a meeting in the Netherlands from Tuesday, **14th April** to Friday, **17th April.** The programme is as follows:

Tuesday, 14th April

2.30–5 p.m.

Technical session at the Grand Hotel Krasnapolsky, Amsterdam. Mr F. B. George, Chairman of the Group, will be in the chair.

Lecture on the world iron ore situation by Mr C. R. Wheeler, C.B.E., President of The Iron and Steel Institute.

Presentation of the following papers:

"*The Muller-Hanna ore-handling installation at the Port of Rotterdam,*" by F. D. Vines.

"*Ore-transfer facilities at Contrecoeur, Quebec,*" by D. H. Sharp.

"*Ore-handling facilities at Seven Islands, Quebec,*" by D. H. Sharp.

"*Transportation and handling of ores in Great Britain,*" by T. V. Nicholson.

"*The unloading of iron-ore ships in the USA and Canada,*" by H. R. Mills.

Wednesday, 15th April

9.30–12 noon

Technical session at the Grand Hotel Krasnapolsky. Discussion of the papers presented on the previous afternoon.

2.30–5 p.m.

Technical session at the Grand Hotel Krasnapolsky. Presentation and discussion of the following papers:

"*Ore crushing,*" by A. Kjelgaard.

"*Screening blast-furnace burden materials,*" by H. N. Wilkinson and E. E. Farmer.

"*Ore handling at Port Talbot,*" by J. Robson.

"*Ore handling at East Moors Works, Cardiff,*" by T. Jenkins.

"*Raw materials handling problems in steelworks.*

"*Part I—General handling problems,*" by H. Swindells;

"*Part II—Ore bedding plants,*" by B. S. Pelton and R. Bartram.

Thursday, 16th April

9 a.m.–10 p.m.

All-day visit to the Royal Netherlands Blast Furnaces and Steelworks Ltd., IJmuiden.

Friday, 17th April
8.56 a.m.–11.30 p.m.

All-day visit to Rotterdam. Visits will be paid to the Rotterdam Dry Dock Co. Ltd., and the Muller-Hanna ore-handling installation.

Preprints of all the papers to be presented, with the exception of Mr Wheeler's lecture, will be available in advance of the meeting. A bound volume of proceedings of the meeting will be published later in the year in the Institute's Special Report Series.

The maximum number of members who will be able to attend the visits to IJmuiden and Rotterdam will be 150; it will, however, be possible to accommodate up to 250 at the technical sessions in Amsterdam. Notices and reply forms have already been circulated.

POWDER METALLURGY JOINT GROUP

Meeting on sintering

The next meeting of the Powder Metallurgy Joint Group is being held at Church House, Great Smith Street, London S.W.1, on Wednesday, **29th April**, starting at 9.30 a.m. A series of papers on "Theoretical aspects of sintering" is to be presented and discussed. All the papers are being published in advance in the next issue of the Group's journal, *Powder Metallurgy*. Visitors are welcomed, and tickets are not required.

On the evening of the meeting there will be an informal conversazione at the offices of The Institute of Metals. The number of tickets is limited to about 200; they will be restricted to members of The Iron and Steel Institute and The Institute of Metals and their personal guests. Applications for tickets should be sent to the Secretary, Powder Metallurgy Joint Group, 17 Belgrave Square, London S.W.1.

There will be a small exhibition of specimens, apparatus, photographs, etc. relevant to sintering at the conversazione. Those wishing to offer an exhibit should communicate with the Secretary at the above address.

BRITISH NUCLEAR ENERGY CONFERENCE

Meetings in March

The Joint Panel on Nuclear Marine Propulsion is sponsoring the meeting to be held on 3rd March at the Institution of Marine Engineers, 76 Mark Lane, London E.C.3, starting at 5.30 p.m. Dr H. M. Finniston is to deliver a lecture on "Metallurgical problems related to nuclear propulsion of ships."

The main event during the month is the lecture symposium on "Geneva, 1958," which is being held at Central Hall, Westminster, on 13th March. The 2 000 papers presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy have been classified into seven groups; leading experts in each field will attempt to highlight the most important aspects of the new information in a series of expository lectures.

The programme is as follows:

MORNING SESSION

9.45–10.30	"*Geneva*, 1958," by Sir John Cockcroft, O.M.
10.35–11.20	"*Developments in physics*," by J. V. Dunworth and others
11.25–12.10	"*Power reactors*," by Professor J. Diamond and others
12.15–1.00	"*Developments in reactor technology*," by H. Kronberger and others.

AFTERNOON SESSION

2.30–3.15	"*Metallurgical developments*," by H. M. Finniston and L. Grainger
3.20–4.05	"*Chemical processes*," by Professor J. M. Kay and others
4.10–4.55	"*Thermonuclear processes*," by D. W. Fry.

Admission is free to members of constituent societies (of which The Iron and Steel Institute is one) and their guests. The papers are being printed in the April issue of the *Journal of the BNEC*.

G. F. Bandel

W. Coupette

L. Mair

CONTRIBUTORS TO THE JOURNAL

C. J. Ball, B.A., PH.D.—Lecturer in Physics, Makerere College, Kampala, Uganda.

Dr Ball was born in Calcutta in 1932 and educated at Truro School and Queens' College, Cambridge, where he obtained a Class I in Part I of the Natural Sciences Tripos in 1952, followed by a Class II in the second part the following year. He carried out research at the Cavendish Laboratory from 1953 until 1958, when he took up his present post. Dr Ball, who obtained his Ph.D. in 1957, was awarded an Andrew Carnegie Research Scholarship in 1954.

G. F. Bandel, DR.PHIL.—Research Department, Bochumer Verein für Gussstahlfabrikation AG, Bochum, Germany.

Gerhard Bandel received his metallurgical education at Gottingen University, where he obtained his doctorate in 1930. For the next four years he was assistant to Professor G. Tammann at Gottingen. In 1934 he became a member of the research staff of Fried. Krupp AG at Essen. He joined the Röchlingsche Eisen- und Stahlwerke, Völkingen, in 1946, where he remained until 1951, when he was appointed manager of the research department of Bochumer Verein. Dr Bandel is especially concerned with the properties and development of alloy steels for high-temperature use.

W. Coupette—Bochumer Verein für Gussstahlfabrikation AG, Bochum, Germany.

Werner Coupette was born in 1908 at Duisburg-Ruhrort, Germany, a member of a family that has been connected with iron and steel production for several generations. He studied ferrous metallurgy at the Technical University, Berlin-Charlottenburg, under Professor Dr R. Durrer, and after obtaining a distinction in his final examination in 1935, joined Bochumer Verein. He took up a post in the works research department, becoming its head in 1942. His doctorate thesis was on the subject of temper qualities of heavy forgings. In the course of further metallurgical researches, principally concerned with gas content and solidification processes of steel, he obtained experience and information that was to prove invaluable when he later turned to the development of vacuum degassing of steel on a production basis.

L. Mair—Senior Metallurgist, Shape Products, Service Department, Inland Steel Company, East Chicago, Ind., U.S.A. (*author of paper in January issue*).

Logan Mair was born in 1916 at Renfrew, Scotland. He received his education at the Hammond public schools, Hammond, Indiana. He joined the Inland Steel Company in 1935 as a tester, and held many positions in the company's metallurgical and research and development department before being appointed senior metallurgist in 1958.

T. F. Pearson, M.SC., F.I.M.—Research Manager, Consett Iron Co. Ltd.

Thomas Pearson was educated at Dudley Grammar School and Birmingham University, where he obtained a first-class degree in metallurgy, being awarded a Wiggin scholarship and a Bowen Research Scholarship. He was subsequently also awarded a Carnegie Scholarship to continue work on graphitization in Fe–C–Si alloys, for which he was awarded the degree of M.Sc.

After working with Bolckow Vaughans as an assistant metallurgist and later assistant melting-shop manager at the Cleveland works, Mr Pearson joined the British Non-Ferrous Metals Research Association in 1936 as a senior research assistant; he was engaged in work on the melting and casting of bronzes and nickel silvers. In 1939 he joined Colvilles Ltd. at the Dalzell Works, later transferring to the Clydebridge Works as plant metallurgist, where his chief interest was in steelmaking and the application of mixed-gas firing to open-hearth furnaces. While with Colvilles, he was awarded a Williams Prize by The Iron and Steel Institute in 1945 for work on the citric acid solubility of O.H. slags.

Mr. Pearson joined his present company as chief technical officer in 1947, and was appointed research manager in 1958. While at Consett he has been principally engaged in the development of new steels and steelmaking processes.

C. F. Schrader, B.S.—Superintendent, Metallurgical Department, Inland Steel Company,

T. F. Pearson

C. F. Schrader

A. Sickbert

M. Tenenbaum

A. Tix

East Chicago, Ind., U.S.A. *(author of paper in January issue).*

Mr Schrader was born at St Paul, Minnesota, in 1923. From 1941 to 1942 he was with the Minnesota Mining and Manufacturing Company, before joining the US Army, in which he served until 1946. On demobilization he entered the University of Minnesota, obtaining a B.S. degree in chemical engineering in 1948. Mr Schrader joined the Inland Steel Company in 1949 as a metallurgical trainee. After holding numerous positions, he was appointed superintendent of the metallurgical department in January this year.

A. Sickbert, DIPL.-ING.—Chief Engineer, Electric and Open-Hearth Steelworks, Plants I and II, Bochumer Verein für Gussstahlfabrikation AG, Bochum, Germany.

Adolf Sickbert was born at Georgsmarienhütte, near Osnabrück, in 1905. After working for four years at the Georgsmarienhütte steelworks, he studied ferrous metallurgy at the Technical University, Breslau, from 1925 to 1930. He worked at three different steel plants before joining Bochumer Verein in 1935.

A. Tix, DIPL. ING., DR. ING.E.H.—Technical Member of Board of Directors, Bochumer Verein für Gussstahlfabrikation AG, Bochum, Germany.

Arthur Tix was born at Darmstadt in 1897 and studied mechanical engineering and iron and steel technology in his home town. He obtained an engineering degree in 1922, and joined Bochumer Verein as a rolling-mill assistant; he ultimately worked his way up to the position of works director for all the "hot" departments of the company. From 1942 to 1947 Dr Tix was Chairman of Hanomag AG and later of Stahlwerk Osnabrück.

He returned to Bochumer Verein in 1950, and under his guidance a new rolling mill and billet-heating plant were built. He was also responsible for the development of the vacuum-degassing process on a production scale, for which he was awarded the Robert W. Hunt Silver Medal of the AIME in 1957. The most recent installation at Bochum with which Dr Tix has been connected is the L–D steelworks, which went into operation at the end of 1957.

Dr Tix was awarded an honorary Dr-Ing. degree by the metallurgy section of the Mining Academy, Clausthal, in 1956 in recognition of his achievements in the field of modern iron and steelmaking.

M. Tenenbaum, PH.D.—Assistant General Manager, Technical Service, Inland Steel Company, East Chicago, Ind., U.S.A. *(author of paper in January Journal).*

Dr Tenenbaum was born at St Paul, Minnesota, in 1914 and educated at the University of Minnesota, where he obtained his Ph.D. degree in 1940. After a short spell with the Tennessee Coal, Iron and Railroad Company, he joined the Inland Steel Company in 1941, and since then he has held numerous positions, including that of assistant chief research engineer. He became assistant general manager of technical services in January this year. Dr Tenenbaum has written over 40 technical papers for various metallurgical journals.

EDUCATION

Lectureship at Sheffield University

Applications are invited for the post of Lecturer in Metallurgy to begin duties on 1st October, 1959, or as soon thereafter as possible. The successful candidate will be expected to take an interest in the scientific aspects of the solidification and fabrication of metals; previous relevant experience would be an advantage. The salary scale starts at £900 rising to £1 650, with FSSU provision and family allowance. Further particulars may be obtained from the Registrar, to whom applications (4 copies) including the names and addresses of at least two referees should be sent by 21st March.

Joint Committee for National Certificates in Metallurgy

The report for 1957–1958 of the Joint Committee for National Certificates in Metallurgy has recently been published. During 1958 there were 728 candidates for the Ordinary National Certificate from 39 technical colleges; of these, 373 were awarded certificates, 47 with distinction. There were 341 candidates for the Higher National Certificate from 26 colleges; of the 269 successful candidates, 28 were awarded distinctions. These figures were the highest for both certificates since their inception in 1946 and 1947 respectively, but the Committee expressed some concern about the unsatisfactory standard of the work of many candidates entering for the Ordinary National Certificate.

NEWS OF SCIENCE AND INDUSTRY

The OLP process

The December, 1958, issue of the *Revue de Métallurgie* contains a paper on the OLP (oxygen, lime powder) process for refining pig iron using pure oxygen and lime powder, developed by the Institut de Recherches de la Sidérurgie. The new paper gives additional information to that given in earlier papers by IRSID workers in Paris (1957), New York (1958), Liège (1958), and Paris (1958).

The new process is a logical outcome of the systematic researches carried out by IRSID for a number of years in the field of the injection of powdered materials. Steel was first produced by blowing lime powder in suspension in pure oxygen by IRSID, and a series of patents has been filed in France and elsewhere. Since the process is a flexible one, in that it can be applied to pig irons of widely different compositions, interest has been shown in the new process by several French and other European steel companies, which suggests that it may have an important future. The Denain works of the USINOR company has already produced about 10 000 tons of steel using the OLP process, and this has been sold commercially as high-quality open-hearth steel, to the complete satisfaction of the consumers. The equipment at Denain is being developed to permit larger tonnages of OLP steel to be produced.

Non-destructive testing

"What industry requires from non-destructive testing" is the provocative title of a discussion meeting organized by the Non-destructive Testing Group of the Institute of Physics. The problem will be examined in three main ways—the types of inspection problem confronting industry, these problems in the light of the present state of non-destructive testing, and the most appropriate approach to meet industry's requirements.

Dr C. Sykes, F.R.S. (Thos. Firth and John Brown Ltd.) will be in the chair, and the invited speakers include Mr E. W. Colbeck (Hadfields Ltd.) and Mr W. C. F. Hessenberg (BISRA). The meeting is being held at the Institution of Electrical Engineers, Savoy Place, London W.C.2, on 13th March, starting at 2.30 p.m. Further particulars may be obtained from The Institute of Physics, 47 Belgrave Square, London S.W.1.

New ESC subsidiary

The permanent magnet business previously carried on by the English Steel Rolling Mills Corporation Ltd. has been transferred to the English Steel Magnet Corporation Ltd. of North Street Works, Openshaw, Manchester, a new wholly owned subsidiary of the English Steel Corporation Ltd. Chairman of the new company is Mr R. G. H. Taylor.

DIARY

2nd Mar.—CLEVELAND INSTITUTION OF ENGINEERS—"*Biological treatment of effluent,*" by J. W. Abson and K. H. Todhunter—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 p.m.

3rd Mar.—BRITISH NUCLEAR ENERGY CONFERENCE—"*Metallurgical problems related to nuclear propulsion of ships,*" by Dr H. M. Finniston—Institution of Marine Engineers, 76 Mark Lane, London E.C.3, 5.30 p.m.

3rd Mar.—SHEFFIELD METALLURGICAL ASSOCIATION—"*The competitive position of the British steel industry,*" by E. T. Sara—BISRA, Hoyle Street, Sheffield, 7 p.m.

4th Mar.—MANCHESTER METALLURGICAL SOCIETY—"*The behaviour of steels during hot working, with particular reference to hot extrusion processes,*" by P. Sukolski—Central Library, Manchester, 6.30 p.m.

4th Mar.—SOCIETY OF CHEMICAL INDUSTRY (Corrosion Group)—"*The diagnosis of the causes of corrosion failures,*" by J. B. Cotton, R. A. Hine, E. E. White, and K. A. Chandler—14 Belgrave Square, London S.W.1, 6.30 p.m.

5th Mar.—EAST MIDLANDS METALLURGICAL SOCIETY—"*Plastic-coated steel sheet,*" by F. H. Smith and W. E. Martin—College of Art, Green Lane, Derby, 7.30 p.m.

5th Mar.—LEEDS METALLURGICAL SOCIETY—"*Metallurgical applications of high-resolution microscopy,*" by Dr J. Nutting—Chemistry Wing, University of Leeds, 7.15 p.m.

7th Mar.—LIVERPOOL METALLURGICAL SOCIETY—Sixth Annual Conversazione—Department of Metallurgy, University of Liverpool, 7 p.m.

9th Mar.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—Annual General Meeting, followed by young members' papers—North Lindsay Technical College, Scunthorpe, 7 p.m.

9th Mar.—NORTH-EAST METALLURGICAL SOCIETY—"*Development of the tungsten filament lamp,*" by Dr B. P. Dudding, M.B.E.—Cleveland Scientific and Technical Institution, Middlesbrough, 7.15 p.m.

10th Mar.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Impact transition temperatures,*" by Dr B. Cina—BISRA, Hoyle Street, Sheffield, 7 p.m.

11th Mar.—NEWCOMEN SOCIETY—"*The Coalbrookdale Group Horsehay Works,*" by Dr R. A. Mott—Science Museum, London S.W.7, 5.30 p.m.

11th Mar.—NORTH WALES METALLURGICAL SOCIETY—"*Oxygen in steelmaking,*" by D. J. O. Brandt—Flintshire Technical College, Connah's Quay, 7 p.m.

12th Mar.—INSTITUTE OF WELDING—2nd Annual Lecture: "*Welding and the nuclear energy programme,*" by Sir Leonard Owen, C.B.E.—54 Princes Gate, London S.W.7, 6 p.m.

12th Mar.—LIVERPOOL METALLURGICAL SOCIETY—"*The rare metals used in atomic energy applications,*" by L. R. Williams—Department of Metallurgy, University of Liverpool, 7 p.m.

13th Mar.—BRITISH NUCLEAR ENERGY CONFERENCE—"*Geneva, 1958,*" a lecture symposium on 2nd International Con-

ference on the Peaceful Uses of Atomic Energy—Central Hall, Westminster, 9.45 a.m.

13th Mar.—INSTITUTE OF PHYSICS—Discussion meeting on "*What industry requires from non-destructive testing*"—Institution of Electrical Engineers, Savoy Place, London W.C.2, 2.30 p.m.

13th Mar.—NORTH WALES METALLURGICAL SOCIETY and ROYAL INSTITUTE OF CHEMISTRY (North Wales Section)—"*Nuclear metals*," by Dr A. B. McIntosh—Flintshire Technical College, Connah's Quay, 7.15 p.m.

13th Mar.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE and THE IRON AND STEEL ENGINEERS GROUP—"*The installation and commissioning of an 80-ton electric-arc melting furnace*," by P. M. Thomas and A. MacNaughton—39 Elmbank Crescent, Glasgow, 6.45 p.m.

15th Mar.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—Annual Meeting—Whitehead Institute, Newport, 7 p.m.

16th–17th Mar.—PEDDINGHAUS FLAME-HARDENING CONFERENCE—Essen, Germany.

16th–20th Mar.—NATIONAL ASSOCIATION OF CORROSION ENGINEERS—Annual Conference—Chicago, Ill., U.S.A.

16th Mar.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS AND SHEFFIELD METALLURGICAL ASSOCIATION—"*The conversion of a high-lift blooming mill to a universal slabbing mill*," by C. E. H. Morris and R. N. Dale—Engineering Lecture Theatre, St. George's Square, Sheffield, 7.15 p.m.

17th Mar.—SHEFFIELD METALLURGICAL ASSOCIATION. (Refractories Group)—"*Refractories usage in steelmaking abroad*," by C. S. Hedley—BISRA, Hoyle Street, Sheffield, 7 p.m.

18th Mar.—LIVERPOOL METALLURGICAL SOCIETY—Visit to Magnesium Elektron Ltd.

18th Mar.—MANCHESTER METALLURGICAL SOCIETY—"*Metallurgical background of casting production*," by A. Cibula—Central Library, Manchester, 6.30 p.m.

18th Mar.—SOCIETY OF CHEMICAL INDUSTRY (Corrosion Group)—"*Economic aspects of corrosion*," by A. Keynes—14 Belgrave Square, London S.W.1, 6.30 p.m.

19th Mar.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*Nuclear power reactors and heat exchangers at Berkeley Power Station*," by S. H. Griffiths—Station Hotel, Dudley, 7.30 p.m.

20th Mar.—EBBW VALE METALLURGICAL SOCIETY—Annual Dinner.

21st Mar.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Annual Dinner.

24th Mar.—INSTITUTION OF NAVAL ARCHITECTS—Annual General Meeting—10 Upper Belgrave Street, London S.W.1, 10.15 a.m.

24th Mar.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—"*Metallurgy in electronics*," by N. R. Howard—Whitehead Institute, Newport, 7 p.m.

31st Mar.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Titanium production and properties*," by J. W. S. Stafford—BISRA, Holye Street, Sheffield, 7 p.m.

2nd Apr.—LEEDS METALLURGICAL SOCIETY—"*Special steel manufacture*," by D. Hall—Low Moor Alloy Steelworks Ltd., Bradford, 7 .15 p.m.

3rd Apr.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—26th Annual Dinner.

5th–10th Apr.—AMERICAN CHEMICAL SOCIETY—135th Meeting—Boston, Mass., USA.

6th Apr.—CLEVELAND INSTITUTION OF ENGINEERS—"*Iron and steel works maintenance*," by A. V. Williams—Cleveland Scientific and Technical Institution Middlesbrough, 6.30 p.m.

6th–12th Apr.—5th METALLURGY-SKIING MEETING—St Christoph am Arlberg, Tyrol, Austria.

7th Apr.—EAST MIDLANDS METALLURGICAL SOCIETY—Annual General Meeting and "*Metallurgical examination of failures*," by G. A. Cottell—Electricity Lecture Theatre, Carrington Street, Nottingham, 7.30 p.m.

8th Apr.—INSTITUTION OF ENGINEERING INSPECTION—"*Control and inspection of resistance-welding*", by C. L. Railton—Birmingham Exchange and Engineering Centre, 6.30 p.m.

9th Apr.—LIVERPOOL METALLURGICAL SOCIETY—11th Annual General Meeting, and "*Boron in steel*," by F. B. Pickering—Department of Metallurgy, University of Liverpool, 7 p.m.

10th Apr.—BRITISH NUCLEAR ENERGY CONFERENCE—"*Canadian atomic energy development in review and prospect*," by W. B. Lewis (James Clayton Lecture)—Institution of Mechanical Engineers, 1 Birdcage Walk, London S.W.1, 6 p.m.

10th Apr.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Symposium on open-hearth maintenance—39 Elmbank Crescent, Glasgow, 6.45 p.m.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on p. 196 of the February, 1959, issue of the *Journal*:

981. BASTIEN, P., and P. AMIOT: "A Method for the Determination of the Coefficient of Diffusion of Hydrogen in Steel. Influence of the Microstructure on this Diffusion." *Rev. Mét.*, 1958, Jan., pp. 24–38. (£6).

1031. WERTHEBACH, P., and H. HOFF: "The Influence of Annealing on the Precipitation of Aluminium Nitride and the Mechanical Properties of Non-alloyed Steels." *Stahl u. Eisen*, 1958, May 29th, pp. 736–743. (£5 10*s*. 0*d*.).

1050. ZITTER, H., and H. KRAINER: "Sampling and Determination of Hydrogen in Steel under Works Conditions." *Arch. Eisenhütt.*, 1958, July, pp. 401–410. (£7).

1054. PLÖCKINGER, E., and A. RANDAK: "Investigations on Banded Structure in Plain Carbon and Alloy Structural Steels." *Stahl u. Eisen*, 1958, July 24th, pp. 1041–1058. (£9 15*s* 0*d*.).

1072. NEUBERGER, F., *et al.*: "Heating without Scale-formation by using Lithium Carbonate in a Miniature Forging Furnace Heated by town gas." *Werkstattstechnik u. Maschinenbau*, 1958, June, pp. 341–343. (£3).

1078. SCHUERMANS, R., and J. VAN NESTE: "Raw (unfired) Converter Bottoms at the Seraing Basic Bessemer Steelworks, Cockerill-Ougrée." *Rev. Univ. Min.*, 1958, Aug., pp. 270–279. (£4 10*s*. 0*d*.).

1097. SHEVAKHIN, YU. F.: "An Analysis of Existing Methods for Calculating the Profile of the Rolls of Cold Tube Reducing Mills." *Stal'*, Rolling and Tube Manufacture Supplement, 1958, pp. 259–275. (£6 5*s*. 0*d*.).

1098. SHEVAKHIN, YU. F.: "The Magnitude and Direction of Axial Forces Acting on the Workpiece in the Cold Reducing of Tubes." *Stal'*—Rolling and Tube Manufacture Supplement, 1958, pp. 295–313. (£6 15*s*. 0*d*.).

1104. UHLITZSCH, H., and G. RADOMSKI: "Use, Manufacture, and Heat Treatment of Alloy Cast Steel Rolls."
I—Stresses which arise in the Heat Treatment of Cast Steel Rolls, and Their Calculation.
II—Materials, Applications, and Casting of Steel Rolls, and Various Forms of Heat Treatment.
I.—*Neue Hütte*, 1957, Nov., pp. 655–663 (£4 10*s*. 0*d*.).
II.—*Neue Hütte*, 1958, Jan., pp. 10–20. (£4).

1107. ENGELHARDT, W.: "Die Stamping and Drop Forging." *Neue Hütte*, 1958, Mar., pp. 165–173. (£5).

1110. KOCH, W., *et al.*: "A Highly Sensitive Determination of Sulphur and Simultaneous Determination of Carbon and Sulphur with a Conductivity Recorder." *Arch. Eisenhütt.*, 1958, Sept., pp. 543–546. (£3).

1115. MAZEL', A. G., and K. K. KHRENOV: "External Characteristics of the Current Source in Welding under a Carbon Dioxide Shield." *Svarochnoe Proizvodstvo*, 1957, (8), pp. 31–34. (£3 10*s*. 0*d*.).

1119. BURDELSKI, T.: "Plastics for Universal Jointed Spindles, Wobbler Boxes and Couplings." *Stahl u. Eisen*, 1958, Aug. 7th, pp. 1110–1119. (£6 10*s*. 0*d*.).

1129. SIEWIERSKI, J.: "Apparatus for Measurement of Losses in Whole Transformer Sheets." *Hutnik* (*Prague*), 1957, July/Aug., pp. 333–334. (£3).

1130. KAUFMAN, M. M.: "The Use of Water-cooled Plugs in the Piercing of Billets." *Stal'*, 1958, Feb., pp. 144–151. (£6 5*s*.0*d*.).

1131. HORSTMANN, D.: "The Adhesive Strength of Zinc Coatings on Heavily Coated, Hard Drawn Wires of Rimmed Low Carbon Steel." *Stahl u. Eisen*, 1958, Oct. 16th, pp. 1456–1462. (£3 10*s*. 0*d*.).

1138. HENSE, L., and H. SCHERUHN: "Practice for Welding Circular Seams on Large Diameter Pipes." (Hand and automatic welding of pipes for oil, water, and gases). *Schweissen & Schneiden*, 1958, May, pp. 162–166. (£4 5*s*. 0*d*.).

1141. HEYNERT, G., *et al.*: "Observations and Experiments on the Reduction of Iron Ores." *Stahl u. Eisen*, 1958, Oct. 30th, pp. 1493–1505. (£9 5*s*. 0*d*.).

1142. HILTERHAUS, W.: "Planning Work for the Construction of a Plate Mill." *Stahl u. Eisen*, 1958, Oct. 30th, pp. 1525–1535. (£8 10*s*. 0*d*.).

1145. LECLERC, L., and J. GOUREAU: "Determination of Nozzle Sizes and Rates Adopted for the Teeming of Drawing Rimming Steel Flat Ingots." *Rev. Mét.*, 1958, Aug., pp. 710–715. (£2 15*s*. 0*d*.).

1148. HACHE, A.: "Stress Corrosion Tests on Mild Steel." *Rev. Mét.*, 1958, July, pp. 656–676. (£7 10*s*. 0*d*.)

1154. WEILANDT, B., and F. KRUSE: "Utilisation of Sludge from Gas Scrubbers." *Stahl u. Eisen*, 1958, Nov. 13th, pp. 1657–1662. (£4)

1159. DEMENTEV, V. M., and M. M. KOTROVSKY: "Investigation of Ingot Cooling." *Stal'*, 1958, Sept., pp. 847–851. (£3).

1161. HEILIGENSTAEDT, W.: "The Völklingen Cross-flow Shaft Kiln, for Burning Small Lump Limestone." *Stahl u. Eisen*, 1957, Apr. 4th, pp. 421–426. (£4 5*s*. 0*d*.)

1174. BOROVKOV, A. N., and E. A. SVETLITSKII: "The Use of Non-changeable Piercer Plugs, in a 400 mm Tube Rolling Plant." *Stal'*, 1958, Oct., pp. 926–927. (£2 10*s*. 0*d*.)

1180. GUTHMANN, K.: "The Problem of Clean Air, with Special Reference to the Iron and Steel Industry." I—Measurement; effects; regulations. *Radex Rundschau*, 1958, Jan., pp. 3–30. (£8 10*s*. 0*d*.)

1183. MATTHAEI, H.: "Oberhausen Plate Mill: Structural Features of a Newly Erected Plate Mill." *Stahl u. Eisen*, 1958, Oct. 30th, pp. 1609–1611. (£2 5*s*. 0*d*.)

1184. MÜLLER, H.: "Directions for the Rolling of Alloy Steels." *Stahl u. Eisen*, 1958, Oct. 30th, pp. 1611–1613. (£2 15*s*. 0*d*.)

1185. ŽIDEK, M.: "The Effect of Quenching from Final-pass Rolling Temperatures on the Properties of Thick Steel Sheet of Ultimate Tensile Strength 52–60 kg/mm² (33–38 tons/sq. inch)." *Hutnik* (Prague), 1958, May, pp. 151–159. (£6 15*s*. 0*d*.)

1191. REMMERSWAAL, J. L.: "Phenomena of Wear on Tools for Chip-forming Machining." *Metaalbewerking*, 1958, (22), pp. 447–451. (£3 5*s*. 0*d*.)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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* Abstracts, the reference to which is marked with an asterisk are made available as translations.

MINERAL RESOURCES

Iron Ore and Other Raw-Material Sources for a Primary Iron and Steel Industry in Western Canada. T. H. Janes. (*Can. Min. Met. Bull.*, 1958, **51**, Sept., 564–573). Ore deposits are reviewed and fuel, limestone, and scrap supplies are estimated for British Columbia. (20 refs.).

Ironstone Occurrence—South of Earea Dam. A. R. Crawford. (*Mining Review, S. Australia Dept. of Mines*), 1956, June 30, 15–18). **Iron Ore Exploration—Middleback Range.** (19).

The Chromiferous Ultrabasic Rocks of Eastern Sierra Leone. K. C. Dunham, R. Phillips, R. A. Chalmers, and D. A. Jones. (*H.M. Stationery Office, Overseas Geology and Mineral Resources Supplement Series, No. 3*, 1958, pp. 44).

Two-Plane Electromagnetic Ore Prospecting. (*Swedish Foreign Commerce*, 1958, (5), 46–47). An airborne system using two aeroplanes is outlined.

ORES—MINING AND TREATMENT

High-Grade Iron Ore at Copper Cliff, Ontario. P. Queneau, E. H. Bracken, and D. Kelly. (*J. Metals*, 1958, **10**, Aug., 527–532). The treatment of the nickel concentrates produced at Copper Cliff is described. An iron concentrate low in nickel is produced by eliminating sulphur in fluid bed roasts, and leaching out nickel at atmospheric pressure in ammoniacal solution. The remaining magnetite is concentrated and pelletized.

On the Leaching of Domestic Chromite Ore in Sulphuric Acid. K. Nishihara, M. Kurachi, and N. Hirota. (*Suizokwai-Shi*, 1957, **13**, June, 265–268). Optimum conditions are tabulated.

Influence of Moisture Content on the Properties of Fine-Grained Mineral Concentrate. U. Runolinna. (*Tidsskr. Kjemi Bergv. Met.*, 1958, **18**, (5), 75–79; (6), 92–98). In experiments connected with the transportability of fine ore concentrates, carried out in a miniature model of a ship's hold, the influence of moisture content on the properties of the concentrate was investigated. Details of the techniques used and results obtained are given.

The Influence of a Double Compression on the Kinetics of the Sintering of Agglomerates of Carbonyl Iron. G. Cizeron. (*Compt. Rend.*, 1958, **246**, May 28, 3060–3063). The effect of the grain boundaries in the elimination of pores in sintered compacts is shown by a double compression double sintering process. Increasing the grain size by treatment in the γ-state after a preliminary sintering in the α-phase reduces pore space and speeds up the densification process. Structures are shown after treatments at 880° and 920° C and after one or two compressions.

Some New Methods of Sponge Iron Production. M. Wiberg. (*Jernkont. Ann.*, 1958, **142**, (6), 289–333; discussion 333–355). A discussion of the theoretical conditions for the reduction of iron ore with CO, H, and CH_4 is followed by a description of 12 processes of current interest; a short account is also given of other proposed methods. The processes are criticized and improvements are suggested in the fuels employed in the Wiberg process and in pelletizing techniques.

FUEL—PREPARATION, PROPERTIES, AND USES

Trends in Present Day Coal Research in the United States of America. A. F. Williams. (*Coke Gas*, 1958, Sept., 360–363, 389; Oct., 426–430). Among other topics, improvements in conventional coking processes and fluidized bed methods are included.

Coal Preparation: The Separation Efficiency of Dense Medium Baths. R. L. Whitmore. (*J. Inst. Fuel*, 1958, **31**, Oct., 422–428).

The Lecocq Coking System. A. C. Bureau. (*Year Book Coke Oven Man. Assoc.*, 1958, 230–243).

Experiments Concerning the Effect of Coking Pressure in Full Scale Operation of Coke Oven Plant. J. L. Lambert, W. J. Lancucki-Pater, and G. W. Lee. (*Year Book Coke Oven Man. Assoc.*, 1958, 303–351).

Mechanisation, Automatic Control and Checking in Coke Works. M. Gottwald. (*Hutn. Listy*, 1958, **13**, (6), 481–490). The scope of automation in the production of coke is surveyed with special reference to existing and projected equipment in some West-European states and the USSR.—P. F.

Studies in Coke-Oven Technology by the U.S. Bureau of Mines. (*Coke Gas*, 1958, **20**, Oct., 408–414, 425).

The Reactions of Sulphur in Coal in the Coking Process. An Investigation With the Radioisotope ^{35}S. H. J. Reintjes. (*Arch. Eisenh.*, 1958, **29**, May, 283–291). By adding the radioisotope ^{35}S to coking coal in the form of calcium sulphate and pyrites, it was found possible to determine the distribution of the coal sulphur in the products of gasification. Coking was carried out in a semi-scale plant under simulated operational conditions. The results are discussed.—L. D. H.

Some Experiments on the Fundamentals of Coking Properties. J. K. Brown, I. G. C. Dryden, D. H. Dunevein, W. R. Joy, and K. S. Pankhurst. (*J. Inst. Fuel*, 1958, **31**, June, 259–273). Chemical factors in the early stages of coke formation are summarized and further experiments are described. The chloroform extraction method for isolating fusible primary pyrolysis products was used to study the effects of preheating, pre-oxidation and blending. Carbonization in a vacuum at 400° C is also described: a coking coal gave a volatile solid product similar in yield and nature to that from chloroform extraction and a non-coking coal (yielding no chloroform extract) also gave similar material. The lack of coking properties in a low-rank coal is shown to be due in part to the greater volatility and thermal instability of the primary pyrolysis products.—D. L. C. P.

Changes in the Pore Structure of Coke during Carbonization and Gasification. A. Cameron and W. O. Stacy. (*Austr. J. Appl. Sci.*, 1958, **9**, Sept., 283–302).

Metallurgical Fuel from Victorian Brown Coal. G. L. Kennedy and D. G. Evans. (*J. Inst. Fuel*, 1958, **31**, June, 242–247). The preparation, properties and probable uses of a char made from Australian brown coal are described. The process involves preparing briquettes and heating them in 3 stages in order to dry them, drive off the volatiles and carbonize them to 900° C. The char is strong, reactive, closely sized and of low ash content. Promising trials have been made with it as cupola and domestic stove fuels and a variety of applications are foreseen. A pilot plant will shortly come into production. Cost may be competitive at £15–20/t.—D. L. C. P.

Characteristics of Turbulent Jet Diffusion Flames. M. W. Thring and E. H. Hubbard. (*Inst. Fuel Symposium Report*, 9th Oct. 1957, A1–A9). **Heat Transfer from Flames in the Steel Industry.** J. H. Chesters and R. Mayorcas. (B1–B5). Work on burners, atomization, and type of fuel is described.

Fuel Efficiency in the Iron and Steel Industry. R. P. Towndrow. (*Iron Coal Trades Rev.*, 1958, **177**, Oct. 10, 864–866). A lecture. Various directions of improvement are noted with a note on instrumentation.

REFRACTORY MATERIALS

Refractory Compounds for Foundries. L. Ferro. (*Fonderia*, 1958, **7**, May, 209–214). [In Italian]. The chemical and physical properties of refractory compounds are discussed and the results of a number of tests carried out on samples are described. The tests include resistance to compression both cold and hot, thermal expansion, and corrosion due to the action of slags.—M. D. J. B.

Silica Structure Studies. VI. On Tridymites. V. G. Hill and R. Roy. (*Trans. Brit. Ceram. Soc.*, 1958, **57**, Aug., 496–510). Two phases in very pure SiO_2 and also with various mineralizers distinguished as tridymite-M and tridymite-S are reported.

Considerations Regarding a Systematic Method for the Determination of Resistance to Thermal Shock. S. Tacvorian. (*Silicates Ind.*, 1958, **22**, July/Aug., 383–390). The author describes tests to show that the fracture of inelastic materials such as ceramics is perpendicular to the axis when subjected to thermal shock. Such fractures increase with rise in temperature and are characteristic for a given material. Resistance to thermal shock can be determined therefore by plotting the resistance to fracture of a test-piece before and after subjecting it to thermal shock at different temperatures.—R. P.

IRON AND STEEL, GENERAL

Recent Trends in Iron and Steel Manufacture. W. F. Cartwright. (*Swansea Met. Soc.*, 1958, pp. 10). Problems of ore transport, the O.H. furnace and its competitors, rolling and galvanizing are briefly referred to.

Present Tendencies in Iron and Steelmaking. R. Damien. (*Industrie Nationale*, 1958, (2), 19–40). Present lines of development in ore preparation, the design of iron and steel making plant, the use of new techniques in steelmaking and treatment are discussed.

Steel Production and Export of Rolled Products. J. Tarnowski. (*Prz. Techn.*, 1958, (8), 342–344). [In English]. The post-war development of steel manufacture and processing in Poland are outlined, and the export of plate, sections, tubes and rails is dealt with.

Soviet Steel Industry. I. H. Such. (*Steel*, 1958, **143**, Sept. 8, 85–90). On the basis of a visit to Russia as a member of a delegation of American steelmen the author reports on economic and technical developments in the USSR and their significance.—A. G.

Problems of the Steel Making and Transforming Industries in Latin America. I. Report of the Latin American Meeting of Experts on Steel Making and Transforming Industries (São Paulo Oct. 1956). (*U.N.O. Publication E/CN.12/425; ST/TAA/Ser. C/24*, pp. 62). A review of proceedings with the opening addresses, summary of proceedings, etc.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Scientists Examine Blast Furnace Operation. (*Iron Steel Eng.*, 1958, **35**, June, 144–145). A brief account is given of an experiment in which the contents of an experimental blast furnace were "frozen" during the ironmaking process. There is the opportunity to examine the full cycle of the transformation of raw materials to iron as it takes place inside a blast furnace.—M. D. J. B.

Automatic Charging Control for No. 3 Fairless Blast Furnace. S. P. Curtis, R. F. Schramm, and D. W. Fath. (*Iron Steel Eng.*, 1958, **35**, July, 73–84). A detailed description of the construction and operation of the newly-installed charging control system is given.

Iron and Steel Mission to Poland and Czechoslovakia. Sintering and Blast Furnaces. General Review. F. Paschal. (*Centre Doc. Sid. Circ.*, 1958, **15**, (5), 1 019–1 027). Blast furnace practice and burden preparation in Poland and Czechoslovakia is discussed and compared with the practice in France, Great Britain, and the U.S.A. **Detailed Review.** (1029–1047). Information obtained during the visit of a French technical mission is given. This includes blast furnace lines and operating data which are presented in tabular form.

Effect of the Physical Properties of Coke on the Working of a Blast Furnace. W. Himsel. (*Stahl Eisen*, 1958, **78**, Sept. 4, 1225–1229; discussion, 1 234–1 235). Trials were conducted on the influence of the physical properties of the coke on the working of a blast furnace. Higher coke qualities led to higher hearth load and more uniform working.—T. G.

Distributing Raw Materials in Blast Furnaces. H. W. Campbell. (*Iron Steel Eng.*, 1958, **35**, April, 116–124). A new blast furnace top is described. The principle of the top is to rotate the hopper fast enough to make one complete revolution in the period of time required for the stock to pass from the skip car into the revolving hopper.—M. D. J. B.

Application of Physico-Chemical Data to Blast-Furnace Practice. G. Quade. (*Stahl u. Eisen*, 1958, **78**, June 12, 829–832). A review of published work on the theory of the reactions in the blast furnace. The results obtained by the use of radioisotopes for studying the reactions taking place in the hearth are mentioned.—T. G.

Development of the Technology of Producing Self-Fluxing Sinter with a Basicity above 1·0 and Trials in the Blast Furnace. G. F. Chub. (*Stal'*, 1958, (10), 884). With sinter of basicity 0·95 the use of the gas stream was improved. The CO_2 content of the top gas was raised by 0·5% and the intensity of working of the furnace was raised 0·5%. Furnace operation could be improved by using a high rate of working and increased coke rate or by a moderate rate of working and a lower coke rate. The production of the sinter is briefly described.—R. S.

Large-Scale Trials for the Smelting of Conakry Ore. I.—Smelting of Conakry Ore in the Blast Furnace. W. Wolf, W. vor dem Esche, H. Wysocki, and O. Steinhauer. (**Stahl Eisen*, 1958, **78**, July 24, 1020–1027). The increase in pig iron production in Western Germany requires the use of ore from new sources. Trials were made with Conakry ore as the ore deposit is extremely large. The ore has an iron content of 54%, is very low in phosphorus, the gangue is mainly alumina, but it has a chromium content of up to 1·5%. Alumina gangue and high chromium content require modification of blast-furnace practice. Details of trials with 100% Conakry ore in the blast furnace are reported, dechroming was best carried by submerged oxygen blowing in the ladle in order not to interfere with conventional converter practice. **II.—Dechromizing of Pig Iron by Refining in the Ladle with Pure Oxygen.** (*Aug. 7, 1100–1107). A process of dechromizing basic converter iron containing about 0·8% Cr in the ladle by blowing pure oxygen into the bath is described. The Cr content was reduced to about 0·1%. The temperature of the bath was controlled by addition of partly reduced mill scale. Oxydation of the accompanying elements is in the order: Si, Mn, V, Cr. Before Cr can be removed all Si and almost all Mn must be eliminated. Some difficulties are met with in this process from the tendency of the slag to become tougher with increasing Cr content, at low operating temperature (1300° C) the oxydation products of the Cr are solid and sparingly soluble in the slag.—T. G.

Mathematical-Statistical Evaluation of Blast-Furnace Data. V. Steinecke. (*Stahl Eisen*, 1958, **78**, Sept. 4, 1229–1235). Scatter of characteristic data is very high in investigations of the performance and working of blast furnaces. Only statistical methods are able to interpret the observed values and can give a meaning to scatter values. Some examples are quoted.—T. G.

Measurement of Gas Temperature in Blast Furnace Operation and its Utilization. Operation and its Utilization. Operation of a German Type Gas Sampler and Its Utilization. M. Nose and K. Kasai. (*Sumi. Met.*, 1957, **9**, Oct., 195–206). [In Japanese]. A German instrument which gives continuous readings of temp., analysis and velocity of the shaft gas is described. The relationship between analysis and temp. is shown, and ideal, normal and abnormal temp. distributions are distinguished. Effects of size and type of burden on gas distribution are described. Burden permeabilities may be estimated from gas pressures, and the instrument is useful for correcting abnormal furnace conditions.

Factors Affecting the Size of the Oxidation Zone in Blast Furnaces, Operated with Wet Blast. O. Farkas. (*Koh. Lapok*, 1958, **13**, Feb.-March, 138–142). The author discusses how the rate of the combustion reactions, the kinetic energy of the blast and other factors affect the size of the oxidation zone in blast furnaces, operated with wet blast.—P. K.

Camera Shows Inside of Blast Furnace. (*Iron Steel Eng.*, 1958, **35**, April, 132–135). The article describes a method of taking photographs of the inside of a blast furnace when this is out for relining.—M. D. J. B.

Recent Developments in the Desulphurization of Iron. A. Brandl. (*Stahl Eisen*, 1958, **78**, June 26, 910–913). The author reviews and discusses the work of Trentini, Wahl and Allard using chalk powder for the desulphurization in the holding furnace and that of Whittenberger, Deacon and Hymes using calcium carbide.—T. G.

Possible Utilization of Blast-Furnace Gas in the Synthesis of Hydrocarbons. H. Kölbel. (**Stahl Eisen*, 1958, **78**, Aug. 21, 1 165–1 169). The combined economy of the coal, iron and chemical industry should use the by-products of one of its branches as raw material for others. The author draws the attention of the chemical industry to the large quantities of blast-furnace gas and in particular to its high CO content for use in the synthesis of hydrocarbons. The aspects and their economics are discussed.—T. G.

PROPERTIES, TREATMENT, AND USE OF SLAGS

Slag Composition and Influence on Blast-Furnace Practice. K. C. Sharp. (*J. West Scotland I.S.I. Paper No. 517*, preprint; 1958, pp. 22). Published data are reviewed and burdening discussed with special reference to British practice. In many instances slags of very high desulphurizing potential are possible and this policy is advocated to reduce the load on steel-making furnaces. The value of increased MgO content is discussed and also the effect of high slag basicity on furnace operation.

Equilibrium Measurements between Carbon-Saturated Mn–Fe–Si Melts and CaO–Al_2O_3–MnO–SiO_2 Slags. E. T. Turkdogan and R. A. Hancock. (*Bull. Inst. Min. Met.*, 1958, **67**, Aug., 573–600). Equilibration with CaO–MnO–SiO_2, Al_2O_3–MnO–SiO_2 and CaO–Al_2O_3–MnO–SiO_2 systems was effected at 1400° C. Also with MnO–SiO_2 slags up to silica saturation at 1 atm CO pressure and also at different pressures at 1 350°, 1 400°, 1 450°, and 1 500°. Silicon activity in the metallic phase and in pure Mn silicates was computed. The effect of Si and Fe on graphite solubility in Mn was shown and some ferromanganese blast-furnace data were compared.

DIRECT PROCESSES

Commercial-Scale Direct Reduction of Iron Ore. (*Chem. Eng. Prog.*, 1958, **54**, Oct., 108). A brief note with illustration of the 200-t per day plant at Monterrey, Mexico is given.

New Processes in Iron and Steel. C. R. Wheeler. (*Steel Rev.*, 1958, Oct., 25–34). A semi-popular account of the L.D., Kaldo, Rotor and electric arc steel processes and low-shaft, kiln, gaseous reduction and jet iron processes.

PRODUCTION OF STEEL

The Fundamental Problems of [the Polish] Metallurgical Industry. F. Kaim. (*Hutnik*, 1957, **24**, June, 213–218). [In Polish]. The author considers the problems of increased steel production (up to 1970) as one of the most fundamental problems of the Polish metallurgical industry.

The properties of iron ores from a new mining district (Zagle bie Leczyckie) are

discussed. The development of zinc, lead and aluminium metallurgy based on Polish ores is briefly discussed.

Steel Plant in Venezuela. M. Gonni. (**Met. Ital.*, 1958, **50**, June, 215–246). A comprehensive description is given of the new 730 000 ingot t year plant now in course of construction in Venezuela. Details are given of the iron ores available and other raw materials, ore preparation, sinter plant, coke ovens, blast furnaces, steel plant, mills, services, range of products and scope for future expansion. The plant is being built by Innocenti; the project was prepared by F.I.A.T.—M. D. J. B.

The Role of Oxygen in the Scrap Yard. N. K. Ganguly. (*Tisco*, 1958, **5**, April, 66–82). The author discusses the preparation of scrap and the various techniques used in its processing. The cutting of scrap is dealt with in detail with emphasis on the developments in the use of cutting by oxygen, particularly with reference to the steel skull and slag encrusted scrap.—L. E. W.

The New Basic Bessemer Steelworks of the Société HADIR a Differdange. (*Acier Stahl–Steel*, 1958, **23**, Nov., 481–486). Full plans of the steelwork of the various shops are shown and the construction and lay-out are discussed and illustrated.

Investigations of Converter Smoke with a View to the Spectrographic Control of Basic Bessemer Processes. H. Knuppel, B. A. Steinkopf, K. E. Mayer, and G. Wiethoff. (*Forsch. Wirts. Nordrhein-Westfalen*, 1957, No. 392, pp. 36). Microanalysis, ultramicroscopy and X-ray and electron diffraction studies of converter fume are reported. Particle size and composition (FeO with Mn and P and alkali carbonates) were measured and correlation with spectra were studied.

The Refining of Basic Bessemer Iron with Oxygen Steam Mixtures and the Properties of the Blown Steels. H. Kosmider, H. Neuhaus, and A. Kruger. (*Forsch. Wirts. Nordrhein-Westfalen*, 1957, No. 458, pp. 50). Higher H_2 content and lower N and P were obtained. Structures are shown and effects of rolling described.

Improvement of the Toughness of Cast Bessemer Steel. E. Piwowarski, W. Patterson, and F. W. Iske. (*Forsch. Wirts. Nordrhein-Westfalen*, 1957, No. 461, pp. 41). The effect of treatment with Mg is examined on the mechanical properties and S content. The alloy of 15% Mg–85% Ni added to molten steel greatly improves impact resistance. Toughness is improved by treatment with pure Mg. Trials with Mg–Fe–Si, Mg–Al, and Ca–Al are also reported.

Hot-Blast Cupola LD Converter Steelmaking. A. Richter, G. Cohnen, and P. Jacobi. (*J. Metals*, 1958, **10**, Sept., 599–604; from *Stahl & Eisen*, 1958, Mar. 6). A description of the installation of a basic hot-blast furnace at Gussstahlwerk Witten to supply an LD converter and O.H. plant with hot metal.

The Oxygen Refining of Cast Iron to Steel. F. Johansson. (*Tidsskr. Kjemi Berge. Met.*, 1958, **18**, (5), 65–71). An outline of the development and operation of oxygen refining processes for steel manufacture, including the LD, Rotor and Kaldo processes.

The Recent Development of New Steelmaking Methods. B. Ulrich. (*Metalen*, 1958, **13**, Sept. 15, 304–312). An outline of oxygen refining processes—LD, Rotor and Kaldo—and a comparison with the converter and O.H. processes are given.

The Pre-Treatment of Hot Metal in Ladles by Steam Oxygen Mixture. Ya. A. Shneerov, A. G. Derfel', A. G. Kotin, M. T. Bul'skii, and A. G. Alimov. (**Stal'*, 1958, (8), 694–702). Steam was used to prevent brown fume formation. Si, Mn, C and S are oxidized but P content is not reduced. Oxidizing and slag-forming additions facilitate oxidation but also increase temperature. Metal losses amount to 0·15%. The blower is shown diagrammatically. O_2 consumption is 4·8 m^3/t and steam, 4 kg at 4·5 atm. Under these conditions 29·5% of the Mn (0·55%) and 7·3% of the C (0·29%) are oxidized. S fell by 0·027% during movement in the jumbo but during injection time it increased 0·003%. The total drop in S is thus 0·024% or 21·2% of that initially present.

The Present Position of the Open Hearth Furnace. G. Grenier. (*Echo Mines*, 1958, May, 296–297). A discussion of duplexing as carried out at Consett and in the U.S. and of sponge iron production by the H and Krupp–Renn processes is followed by an account of studies on the O.H. process in Great Britain and the U.S.S.R. Oxygen enrichment is briefly considered.

Innovations in Open Hearth Furnace Firing. M. Korolev. (*Stal'*, 1958, (7), 607–608).

The Life of the Lining of Open Hearth Furnaces Working on Oxygen. E. I. Koval'chuk and G. I. Popov. (*Stal'*, 1958, (10), 890–893). The use of O_2 has a particularly adverse effect on the lining. Life can be increased by installing compensation for linear expansion of magnesite-chrome brick in the roof suspension system; replacing the dinas lining of the slag pocket roofs in part by magnesite-chrome; facing the checker walls with chrome-magnesite; increasing the height of the space under the checkers and cleaning the checkers during the campaign; and by improving the density of the roof bricks and ensuring volume stability at 1700° C. Data are tabulated showing roof life for various methods of using oxygen.—R. S.

The Durability of Chromite–Magnesite Vaults in Open Hearth Furnaces in Poland. Z. Satczek. (*Hutnik*, 1957, **24**, Oct., 387–391). [In Polish]. The durability of chromite–magnesite vaults, imported from Austria, Hungary, Czechoslovakia or produced in Poland was investigated. The results obtained indicate that the durability of the Polish vaults is somewhat lower than that of the imported ones. Recommendations for improvement are put forward.

Brief Notes on Metallurgy. A. D. Marsico. (*Tecn. Industr.*, 1958, **37**, Apr., 363–4). [In Spanish]. Comments are made on various topics, and these include: I. a comparison of Bessemer and O.H. steels; their advantages and disadvantages; II. the work-hardening properties of Hadfield's manganese steel and its uses; III. the stabilised austenitic steels; IV. the limitations of plain carbon steels for high-temperature, sub-zero or tool steel applications; V. the sub-zero treatment of retained austenite in alloy tool steels and VI. the use of high nickel or stainless steels for low temperature conditions.—P. S.

Novel Oxygen Plant Serves New Steelmaking Process at Jones and Laughlin. (*Ind. Heat.*, 1958, **25**, (4), Apr., 748–750). The plant at the Aliquippa works has a capacity of 230 t day. Several storage systems are used and the design is highly efficient.

Tonnage Oxygen. (*Engineer Foundryman*, 1958, **22**, (12), April, 37). Existing tonnage oxygen plants are briefly described.

Application of Hydromechanical Controls in the Iron and Steel Industry. D. Ripamonti. (*La Technique Moderne*, 1958, Jan., 21–25). Applications are classified under the headings: control of cyclic operations, movement of large masses, precise control of conditions and miscellaneous work. Several examples of hydromechanical controls are described.

Republic's Expansion Programme Nears Completion. (*Iron Steel Eng.*, 1958, **35**, Jan., 196–199). The Cleveland plant is being expanded by an annual capacity of 788 000 to 3,360,000 (short) ingot tons. The programme includes 375-t O.H. furnaces, a 45-in. universal slabbing mill, soaking pits, straight approaches to the 98-in. hot strip mill and a coke-oven battery.—K. E. J.

A Study of Side-blown Basic Bessemer Steel. Wu Chao-wang and Pai Chao-kung. (*Acta Met. Sin.*, 1957, **2**, (3), 237–247). [In Chinese]. Side-blown basic Bessemer steel has mechanical properties above the minimum specified, but is inferior to acid Bessemer and O.H. steels because of the higher nitrogen content (0·008%). A new chemical specification is proposed. The amounts of nitrogen and non-metallic inclusions depend largely on the amount of residual carbon at the end of blowing. The practice of overblowing and re-carburizing in the ladle should be avoided. (15 references).—K. E. J.

Oxygen-blown Steel: New Plant in U.S.A. (*Iron Steel*, 1958, **31**, Mar., 107–108). Two 50-t top-blown converters, with a total annual rated capacity of 750,000 t, are now in operation at the Aliquippa Works of Jones & Laughlin Steel Corp. Details are given of the design and lay-out of the plant and its auxiliary equipment.—G. F.

J. & L. Starts Oxygen Steelmaking Process at Aliquippa Works. (*Iron Steel Eng.*, 1958, **35**, Jan., 191–194). Details are given of the new top-blown converter process installed by Jones and Laughlin. The converter-shaped vessel is charged with hot metal, scrap, etc. and blown above the bath surface by oxygen from a water-cooled probe. This produces FeO, which reacts vigorously with carbon in the metal. A heat of at least 54 (short) tons requires 37 min. and the two furnaces have a total rated capacity of 750,000 t year.—K. E. J.

Basic Laboratory Converter with Continuous Bath Temperature Measurement and Second-Change Point Determination. W. A. Fischer and M. Wahlster. (**Stahl Eisen*, 1958, **78**, May 15, 646–654). The development of a 250-Kg. capacity converter is described. The reactions taking place in this converter are similar to those in plant converters. The reactions during the blowing of basic iron in relation to oxygen addition and temperature for various iron compositions were studied. The temperature measurement may be used for the second-change point determination from the differential plot of the recorded temperature curve.—T. G.

The Fumes Evolved from the Converter as an Indicator of the Refining Progress During Blowing with Oxygen-Enriched Blast. L. von Bogdandy and H. D. Pantke. (**Stahl. Eisen*, 1958, **78**, June 12, 792–798). Samples taken from the bath of a basic converter during the last two minutes of blowing were analysed and the results correlated with the simultaneous analysis of the waste gases. The latter were analysed for dust content (20–60 mm g m^3), chem. composition and grain size. The dust consists mainly of iron globules 10–100 mμ in diameter, P and Mn contents are proportional to those of the bath. For the analysis of the dust, an optical apparatus using monochromatic light was developed.

Optical Measurement of Temperature During the Refining of Steel in the Converter. P. Holler and H. Smit. (**Stahl Eisen*, 1958, **78**, June 12, 799–804). Two devices for the temperature measurement of the bath in converters are described: (i) For measurement through the converter mouth. For various reasons this method is not satisfactory; (ii) For measurement through the blast inlets in the converter bottom. Two modifications of this type of apparatus are illustrated, both work on the principle that the intensity ratio of two emitting spectral lines is a function of the temperature of the emitter only. Apparatus is described in detail.—T. G.

Applicability of the LD Converter Process to High-Phosphorus Iron. H. Trenkler and R. Rinesch. (*Stahl Eisen*, 1958, **78**, June 26, 883–890). The authors report on successful trials in a 30-t capacity basic converter in the blowing of iron with a content of up to 1·5% P by the LD process. With up to 0·5% P in the iron the usual LD process is applicable, with higher P contents double slagging is necessary, thus involving a lengthening of the blowing time of up to 12 min. The contents of the finished steel varied between 0·012 and 0·048% P.—T. G.

Top Blowing with Oxygen in Basic Converters. S. I. Lifshits and S. G. Afanas'ev. (*Metallurg*, 1958, (5), 12–16). The Petrov plant has carried out trials with 20-t converters. Metal composition, slag and metal temperatures and the relations between P content of steel and iron oxide content of slag and of gas composition are given. Slag basicity was 2·5–3·1. It is concluded that the note of C consumption in the first 3 min. is 0·171% C/min. and afterwards greater; that O_2 consumed per 0·1% C varies greatly during the process; that most of the P is removed in the first 3 min.; that Mn reduction begins at the beginning of the second period,

at the end, when C is low, Mn is again oxidized; Si is oxidised in the first few min.; S decreases 26·3%, but after lime addition it increases somewhat; N_2 is reduced; slag of normal basicity is formed in the last 3–5 min.; increase of oxide content at the end of the blow is due to the fall in C and Mn increase in the slag is evidence of reaction with the lining.—R. S.

Kinetics of Slag–Metal Reactions. T. B. King. (*Journal of the Metallurgical Club*, 1957–8, (10), 35–40). A thermodynamic treatment of the subject, so far as it is known at present, is given.

The Centenary of Regenerative Firing: The History of the Open-Hearth Furnace. F. Bartu. (*Stahl Eisen*, 1958, **78**, May 29, 713–733). This is an extensive review of design and construction, lining, type of firing and fuels, cooling, charging, the duplex process, use of oxygen and of the theory of O.H. furnaces, with an accumulated bibliography.

The Introduction of Suspended Roofs in Open Hearth Furnaces. K. Leitner. (**Radex Rund.*, 1958, May, 146–153). After describing the development of the suspended roof the use of the suspended basic flat roof in fixed and tilting furnaces is discussed, with an account of results obtained in practice.

Russian Automation of Open Hearth Production. A. K. Adabash'yan. (*Metallurg*, 1958, (5), 1–3). Work is proceeding by study of the O.H. furnace as a thermodynamic unit, by study of the factors determining melt down rate, slag formation, C oxidation, removal of S and P and increase of metal temperature and gas content. Mechanization and automation of technological operations and the development of the necessary controlling and recording instruments is also proceeding. 62 new O.H. furnaces are to be built in 1959–1965 and all existing furnaces will be fully automated.—R. S.

Basic-Bessemer Steel with Interrupted Rimming Action Obtained by Mechanical Capping. J. Duflot, P. Mathieu, and A. Richard. (*Rev. Mét.*, 1958, **55**, Mar., 275–300). Results of a comprehensive study of the capping of basic Bessemer steel are discussed. With Basic Bessemer steel it is possible to produce capped ingots with a moderate addition of Al (110 gms/tonne). With a time of contact of the cap of the order of 2 mins. the piping in the head is very limited and can be of the order of 2%. The head bloom is very regular and the mechanical and chemical properties are more uniform.—B. G. B.

Proposal for the Substitution of Scrap in Steel Making Plants. C. B. Schmidt. (*Second National Congress of the Iron and Steel Industry*, [Mexico], 1957, 267–269). Modern methods of treating iron ore or pig iron, to make charges suitable for electric arc furnaces, are described briefly. **Use of Basic Materials in the Construction and Maintenance of Open Hearth Furnaces.** G. Gomez Colmenares (247–249). Details of the use of basic refractories in steel making practice at Monterey are provided. **Heating Practice for New Roofs in Open-Hearth Furnaces.** M. Dominguez (221–225). The rapid, 12h working up technique at the Altos Hornos de Mexico Co. plant is described. The time saved is equivalent to an extra 4761 t of steel per year. **The Economic Future of the Electric Arc Furnace in Mexico.** W. B. Wallis (227–232). The development of arc furnace steel making in Mexico is described and the scrap problem discussed. New fields of application are considered.

The Position of the Open Hearth Furnace. G. Grenier. (*Echo Mines*, 1958, June, 369–371). Refractories and methods of construction and suggested designs combining oxygen treatment, and continuous working proposals are outlined.

Basic Open Hearth Steelmaking in the United States. M. W. Lightner and D. L. McBride. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 15). Factors in the increase of O.H. steel production are reviewed and the outlook for the future is surveyed.

The Driving Rate of Open Hearth Furnaces. R. W. Evans, J. M. Chesters, A. J. Kesterton, J. F. Allen and J. Pearson. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 13). Comparisons with pneumatic processes are made. The production from the O.H. has increased mainly by increase of size. The possibilities of increasing driving rate are considered based on increased fuel rates and the use of basic refractories, use of O_2 for decarburization and flame enrichment and other factors.

[Improvement in Port Design in the U.S.S.R.] V. F. Isupov. (*Stal'*, 1958, (4), 376). A design in which hot air is injected through a special by-pass into the end of the gas port is described. Regenerative air enters through three apertures with cross-sectional areas of, above the port, 0·75 m², and, the two lateral apertures, 0·28 m². Air is heated in the by-pass to 895–920° and is consumed at 350–370 m³/h. The total feel (1650 m³/h) is 9·7% of the total air consumption of the furnace. Fuel consumption is increased by 2·7–3·7 kg/t and tap-to-tap time is reduced by 10–30 min., raising hourly productivity by 3·8%. Wear of the by-passes due to dust deposit is rapid. A new port without by-pass and apertures has been developed in which hot air enters through two injectors installed in the walls of the air uptakes. The critical cross-sectional diameter of the injector nozzle is 15 mm.

Controlling Thermal Conditions by Maintaining Maximum Heat Absorption in the Open Hearth Bath. G. M. Glinkov. (**Stal'*, 1958, (4), 370–376). Mathematical. It is concluded that specific heat absorption of the bath and the coefficient of useful activity characterize the thermodynamic operation of the O.H. furnace. Determination of the former during a heat shows up changes in the latter. The necessary instrumentation can be used for a system of automatic control. Many thermal characteristics are shown graphically.—R. S.

Two-layer Furnace Hearth. V. Ya. Monastyrskii, A. N. Glazov, and N. D. Kibenko. (*Stal'*, 1958, (4), 331). A note on the production of stainless steel at Kuznetsk. Hearth and banks were covered with a thin layer of chrome ore and, after each heat, were fettled with the same material, magnesite and ferruginous roasted dolomite in the proportions 2:1:10. This gave a thick magnesite layer and a thin burnt-on layer of fettling mixture. This increased the life of the hearth from 830 to 2000 heats. The same process was adopted at the Dnyepro plant.—R. S.

All-Basic Lining Using Chrome Magnesite Bricks in the "Downstairs" Portion of the Open Hearth Furnace. P. S. Maksimov, I. B. Sharykin and A. F. Starkov. (*Stal'*, 1958, (5), 416). The bricking of the roofs of slag pockets and the roofs leading from slag pockets to regenerators on metallic strip with pin fastenings and bricking the walls underneath without suspension arc was used. Also chrome-magnesite was to be used for the bottom of the uptakes. This increased slag pocket volume and simplified cleaning while in the absence of silica lining the deposits were easier to remove.

The Feeding of Compressed Air into Open Hearth Furnace Flames. A. D. Kutsenko. (*Stal'*, 1958, (5), 415). The Dzerzhinsk plant tried passing compressed air into the flame through tubes through the water-coolers of the ports, into the end of the port with air induction from the atmosphere and through tubes at the side of the port. The first method improved productivity by 7%, the others by up to 3%.—R. S.

New Trends in Firing Practices for Open Hearth Furnaces. J. E. Goodin. (*Blast Furn. Steel Plant*, 1958, **46**, Apr., 389–390). A short account is given of the successful replacement of steam by natural gas for atomising oil fuel in O.H. furnaces at the Granite City Steel Co., U.S.A.—B. G. B.

High Temperature Heating of Air in Radiation Recuperators. N. Yu. Taits, Yu. I. Rozengart, A. A. Sorokin and B. L. Poletaev. (*Stal'*, 1958, (5), 472–479). The analysis of the conditions of heat exchange in radiation recuperators and calculations by the methods here given allow a comparison of various types of recuperators. The best for soaking pit operation is shown to be the uniflow type with two directional heating.—R. S.

The Use of High Basicity Sinter when Producing Steel from Phosphoric Irons in the Open Hearth Furnace. I. V. Raspopov, Ya. S. Gorbanev, and F. F. Sviridenko. (*Stal'*, 1958, (4), 306–311). Production of sinter of wide self-fluxing range from low-Si ores can be carried out. Highly basic sinter is lower in melting point, especially lower than ore. In the O.H. with phosphatic pig-iron it reduces tap-to-tap time by 83 min. on the average and increases the P content of the slag.—R. S.

The Use of Ore Briquettes when Transforming High-Phosphorus Pig Irons into Steel. M. T. Bul'skii, F. F. Sviridenko and N. T. Berilov. (*Stal'*, 1958, (4), 303–306). Briquettes of rich fine ore or concentrates and limestone improve dephosphorization and reduce tap-to-tap time. In the O.H. reduced Si content is important as this increases dephosphorization also. An empirical equation is given connecting $[P_2O_5]$ with $[SiO_2]$. As large ores are short in the Ukraine low silica fines were briquetted instead. These contained 5% SiO_2, 4·3% FeO and 64·6% total Fe.—R. S.

The Use of High Basicity Sinter and Briquettes in the Open Hearth Furnace. A. D. Kutsenko. (*Stal'*, 1958, (5), 415). The Dzerzhinsk plant claimes improvement in labour utilisation in the stock yards, quicker slag formation, reduced (10–15%) tap-to-tap time and (30–40%) refining period as S is removed more rapidly.—R. S.

Oxygen-refining in the Open Hearth: SCW Using Back-Wall "Gun" at Margam. Steel Co. of Wales Ltd. (*Iron Coal Trades Rev.*, 1958, **176**, May 30, 1279–1281). A diagram of the installation and a short account of operation and statistics of sulphur removal are given.

Model Tests on Flow in Open Hearth Furnace Checkers. M. Hansen. (*Stahl Eisen*, 1958, **78**, June 12, 804–812). Pressure distribution in flow through models with various ratios of ingoing area to free flow area was measured. This ratio is shown to be of great importance, decrease increases the quantity of flow towards the checkers at the other end of the distributor channel. At the exit the pressure variation becomes greater with increase of this ratio, pressure drop increases towards the exit and distribution becomes non-uniform.—R. S.

Experience with the B.I.S.R.A. Burner in Oil-Fired Open-Hearth Furnaces. K. Schermer. (*Radex-Rund.*, 1958, Jan., 36–41). Comparative trials are described between the B.I.S.R.A. and another type of burner. Two all-basic 110-t furnaces were used for the trials, which were carried out on 200 heats (100 in each furnace). Substantial increases in melting rate and production were achieved by the use of the B.I.S.R.A. burner.—L. D. B.

Eliminating the Noise of Injectors in Open Hearth Furnaces. V. N. Kazantsev. (*Stal'*, 1958, (6), 511–512). Injectors working with compressed air in the ports of O.H. furnaces at Kuznetsk were silenced by means of a simple suction air tube absorber device.

Quality Steels and Sulphur Control in Open Hearth Furnaces. N. Morales. (*First National Congress of the Iron and Steel Industry* [*Mexico*], 1955, 181–186). Origins of sulphur and its removal in the furnace are discussed. The author details the desulphurization procedure in use in his department. **Bottom Pouring in the Steel Making Department of Altos Hornos de Mexico.** M. Ruiz Esparza (175–180). A brief account of the casting and solidification of ingots is given. Problems that might arise with bottom pouring are listed, solutions are given. **The Electric Arc Furnace.** C. W. Vokac (287–289). The advantages of this furnace are described. **Development of the Scarfing Process for Dressing Steel.** H. R. Pufahl. (313–330). Details and illustrations, are given.

Dust Formation in Open Hearth Furnaces when Oxygen is Used to Speed up the Process. Yun Son Chol and E. V. Abrosimov. (*Stal'*, 1958, (6), 506–509). Addition of water as well as oxygen to the blast considerably re-

duces dust formation. Dust content and properties in waste gases during O_2 blowing are described.—R. S.

The Largest Steelworks Arc Furnace in Europe. (*J. Four Elect.*, 1957, **62**, Nov.-Dec., 207–208). Dimensions and other technical details are given of the large electric arc steelmaking furnace at Charleroi, Belgium.

Progress in Electric Steelmaking. Developments at Brymbo Steelworks. (*Iron Coal Trades Rev.*, 1958, **176**, May 23, 1219–1220). An account of the use of oxygen and the plant being installed is given.

Electric Smelting of Iron Ore: Developments in Norway. K. Sandvold, F. C. Collin and J. Gundessen. (*Iron Coal Trades Rev.*, 1958, **176**, May 9, 1099–1101). The 20-MW furnaces for iron ore reduction are outlined with notes on the use of furnace gas.

Results Obtained with a 150-ton Electric Furnace. G. Stassin. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 5). A "Lectromelt" furnace installation 24 ft in dia. at the hearth with a magnetic stirrer is described. The whole process of preparing a cast, taking 6 h is described and an average campaign is outlined. Electrode and power consumption and refractories use are estimated.

Large Electric Arc Furnace Steelmaking Experience in the U.S.A. A. C. Ogan and D. J. Carney. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 10). Trends in furnace design, practice in the production of plain C steels, and a statistical review are given.

Improvement of the Quality of the Electrode Composition Used for Self-Caking Electrodes. V. V. Rukavishnikov. (*Stal'*, 1958, (3), 281–284).

Comparison of Methods of Melting 18% Chromium Nickel Vanadium Steel in Arc Furnaces. V. K. Petrov, A. P. Kopeikin, and E. D. Mokhir. (*Stal'*, 1958, (4), 326–330). Details of trial heats and the best method found (alloy scrap and O_2 blow) are given.

Considerations of Control Systems for Electric Arc Furnaces. S. J. Celada S. (*First Nat. Congress Iron and Steel Ind. [Mexico]*, 1955, 305–311).

The Graphite Rod Resistor Furnace. T. A. Cosh and L. W. Sanders. (*Journal of the B.S.C.R.A.*, 1957, Dec., reprint pp. 9). A 15-cwt installation is described, and its use in steelmaking and remelting.

Transformers for Electric Furnaces. W. M. Bogert. (*Blast Furn. Steel Plant*, 1958, **46**, Apr., 377–378, 388). A short review of the design of transformers for use with large electric furnaces is presented.—B. G. B.

Selection of Arc Furnace Transformers with Consideration to Maintenance. E. G. Ashbaugh. (*Blast Furn. Steel Plant*, 1958, **46**, May, 478–481, 488). A critical review is given of the advantages and disadvantages of a number of methods of cooling large transformers. The maintenance of the transformers is also discussed.—B. G. B.

Rectifier Characteristics and Their Application in the Steel Industry. J. R. Morán. (*Second Nat. Congress of the Iron and Steel Industry [Mexico]*, 1957, 153–181).

On the Secondary Reactances in Electric Arc Furnace Circuits. R. Arias. (*Second Nat. Congress Iron and Steel Industry [Mexico]*, 1957, 271–273).

The Effect of the Mould Making Process on Ingot Mould Life. N. I. Pavlovtseva, and L. M. Cherkasov. (*Stal'*, 1958, (6), 569–574). Various defects are described.—R. S.

Teeming Steel with Vibration. V. F. Isupov. (*Stal'*, 1958, (6), 517). Work at the Serov plant with a view to increasing ingot density and reducing non-metallic inclusions on 3 and 4·25 t ingots by vibrating during solidification of uphill-cast ball bearing steel at 1000 cycles/min. and with an amplitude of 1–2·5 mm obtained no good results.—R. S.

Gas Heating of Feeder Heads. K. N. Konovalov, N. K. Korneva, P. M. Danilov, L. I. Teder, T. T. Drobyazko and A. S. Shtepa. (*Stal'*, 1958, (4), 311–316). Work on stainless steel showed that thermal conditions have a decisive effect on Ti loss and on steel macrostructure. Tests on 6·5 t ingots showed the best conditions for avoiding loss of Ti to be the use of O_2 for 30–60 min. with 6 atm. pressure in front of the burners or 20–30 min. at 3–4 atm. Total heating time was 90–110 min. depending on the level of metal in the feeder head.—R. S.

Organisation of Work in the Casting Pit of an Open Hearth Melting Shop. N. V. Zaveryukha and L. A. Volkov. (*Metallurg*, 1956, (6), 23–26). The following problems are briefly discussed: the distribution of equipment and organization of work in a casting pit, refractory work which should be carried out in the pit, the removal of slag and waste and the operation and maintainance of the pit equipment.—V. G.

Preparation of Hot Steel-Pouring Ladles for Receiving the Heat. G. M. Guzeniel'd and L. G. Korolev. (*Metallurg*, 1957, (12), 24–25). A brief account is given of the preparation of pouring ladles for the next heat without their preliminary cooling. Skulls are melted out with the aid of O_2 and the whole series of operations occupies about 1/3 of the time required with cooled ladles.—S. K.

Organisation of Work on the Preparation of Steel Casting Ladles. L. A. Smirnov. (*Metallurg*, 1956, (**5**), 28–29). Some modification in the design of ladles and the practice used for their preparation for casting as well as the practice used for their partial and complete repair are outlined.—V. G.

Steel Casting Ladles and Their Operation. L. A. Volkov and N. V. Zaveryukha. (*Metallurg*, 1957, (1), 37–39). Some characteristic features in the design and operating practices used on various works are discussed.—V. G.

Mechanisation and Automation of the Teeming of Steel. A. P. Varchavskii and A. N. Fotev. (*Metallurg*, 1956, (5), 39–41). The possibility of the mechanization and automation of the operation of teeming steel is discussed. Mechanical, electrical and pneumatic solutions of the problem are suggested.

Top Teeming of Steel Through Two Stoppers. I. A. Tkachenko, E. I. Dikshtein, A. P. Varshavskii, A. Ya. Goncharevskii, A. G. Nikolaev and P. G. Chernogrud. (*Metallurg*, 1956, (5), 29–32). A description of the equipment is given and the organization of work during teeming of steel through two stoppers, the influence of the method of teeming on the main production indices and the quality of metal are discussed.—V. G.

Nozzle Changes Pay Off. (*Steel*, 1958, Apr. 21, 144–146). Factors involved in selecting steel pouring nozzles are discussed. Bigger nozzles give better ingot surfaces. Refractoriness should lie between PCE 16 and 23 and a close watch must be kept on nozzle quality.—A. G.

Study of the Hydrodynamics of Molten Steel at Teeming or Tapping. Y. Koike. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 122–128). [In Japanese]. Flow studies using mercury, water and aqueous solutions established the conditions of head and physical properties of liquids necessary to give a stable laminar flow. Nozzles for pouring steel have been designed from these data; they have a taper at the entrance and a short parallel portion at the outlet.—K. E. J.

Study on Ingot-Making Practice. V. Effect of Oxidation of Molten Steel by Air on the Non-metallic Inclusions in Steel. 3. Oxidising Velocities of Various Elements and Reciprocal Effect of Various Elements on the Oxidation. S. Mackawa and Y. Nakagawa. (*Tetsu-to-Hagane*, 1957, **43**, Nov., 1216–1222). [In Japanese]. Al was oxidized more rapidly than other elements, and its presence reduced the amounts of SiO_2, MnO and FeO. Carbon was next in order, the oxidation varying with temperature. Oxidation by air during pouring is the main cause of non-metallic inclusions in high-Al steel, but not in high-C steel.—K. E. J.

Moulded Exothermic Linings for Hot Tops. H. D. Shephard. (*A.I.M.M.E. Elec. Furn. Steel Conf. Proc.*, 1956, **14**, 184–200). The use of the Al-based compound "Feedex" is described and illustrated, and the use of clay hot tops lined with mouldable exothermic material and of permanent hot tops is discussed.

Development of Continuous Casting. F. Arkos. (*Koh. Lapok*, 1957, **12**, June, 234–239). A comprehensive review is given of the latest development of continuous steel casting in Western countries and the U.S.S.R. The cross section of the product is between 50 × 50 and 600 × 140 mm. The output is 1 to 36 t per h. The yield of alloy steels has increased by about 10%. For various reasons it is not expedient to use a larger cross section. Thus the best way to increase output may be to employ simultaneously more casting devices; the molten steel being teemed from one ladle through a tundish of appropriate construction.—P. K.

France in the Forefront of the Development of Continuous Casting. (*Aciers Fins Spec.*, 1957, Dec., 21–24). This paper summarizes the types of castings made by the continuous process and discusses the advantages and disadvantages of this method. (25 references).

Discussion. The Horizontal Method of Continuous Casting. V. M. Strelyets. (*Odessa Conference on Continuous Steel Casting*, 1955. Typescript, pp. 11). Defects in refractories are noted. An account of inter-works difficulties is given. G. P. Ivantsov. (3–4). The Goldobin machine is recommended and its operation, difficulties and improvement are discussed. N. N. Dubrovsky (4–6). More about the Goldobin (horizontal casting) machine is reported. M. F. Goldobin (6–7). A. A. Khabakhfeashev. (7–9). Economic topics are mentioned. K. I. Gostyev. (9–10). The point of view of the Ministry of Defence, condemning the horizontal type, is stated. I. P. Bardin. (10–11). Summing up and decisions.

Gas Problems in the Solidification of Steel. T. B. King. (*A.I.M.M.E. Elec. Furn. Steel Conf. Proc.*, 1956, **14**, 159–173). The laws of solution are formulated and free energy values are tabulated. As a practical problem, gas evolution from rimming steels, semi-killed and killed steels is reviewed.

Examination of Chrome Nickel and Straight Chromium Stainless-Steel Ingots. J. C. Fulton and R. H. Henke. (*A.I.M.M.E. Elec. Furn. Steel Conf. Proc.*, 1956, **14**, 92–115). **Solidification of Stainless Steel Ingots.** D. J. Carney and B. R. Queneau. (116–123). Two thorough investigations of ingot macro and micro-structures are reported. Segregation of elements, porosity patterns and the effects of addition of metal powders are shown. Nucleation processes are discussed.

Relation of Ingot Structure to Transverse Ductility of Heat-Treated High-Strength Steel. J. V. Russell and C. R. Weymueller. (*A.I.M.M.E. Elec. Furn. Steel Conf. Proc.*, 1956, **14**, 147–159). Blooms from 170-t heats from basic electric furnaces were examined, melted to aircraft quality standard using the double slag process. These were rolled to ingots and tests were obtained by pressing sections cold-sawed from the same blooms after rolling. The ductility was found to vary with location, relatively high in the columnar zone and low in equiaxed zones.

Influence of the Section of the Ingot on the Properties of the Metal. G. de Rousiers. (*Centre Doc. Sidér. Circ. Inform Tech.*, 1957, **4**, (12), 2439–2440). The results of tests carried out indicate that ingots of square section have better internal structure than those of rectangular section.—B. G. B.

Shrinkage and Density of Liquid Killed Steel in Hot-Topped Ingots. L. H. Nelson. (*A.I.M.M.E. Elec. Furn. Steel Conf. Proc.*, 1956, **14**, 142–159). Shrinkage in the outer shell is about 9·1%, total shrinkage about 11·1%. The density of many steel compositions as poured is ~ 0·2511 lb/in³ and the unequal shrinkage observed across a section depends greatly on the contour of the mould cavity. Forging decreases the difference by closing voids and also produces banding in the columnar zone. These have opposite effects but the columnar zone remains the more ductile under the conditions used.

Influence of the Chemical Composition of Cast Steel on Hot-tearing Tendency. II. S. Oki. (*Tetsu-to-Hagane*, 1957, **43**, Dec., 1293–1298). [In Japanese]. A new type of hot-tearing test ("C" type) is described; in this, increase in carbon, and of Cu to 1·5% do

casting grey and malleable iron, a single charging mechanism for two cupolas was

decrease in specific consumption if full use is made of the melting capacity of the furnace

described. The properties of sands at elevated temperatures are discussed with respect to the

not increase the tendency to hot-tearing. Increasing Al to 1% does not affect the tendency in a steel containing 0·01% S, while additions of 0·1–0·2% Al decrease the tendency in steels containing 0·03% S. (12 references).—K. E. J.

Production of Semi-Killed Steel. L. M. Efimov, D. A. Litvinenko, V. K. Barzu, A. I. Marinov, and V. I. Yakushin. (*Stal'*, 1958, (10), 885–890). Semi-killed steels with 0·08% and 0·20% C were produced by deoxidizing rimming steel in ingot moulds. Microstructure and mechanical properties of the hot and cold rolled sheets were similar to those of the corresponding rimming steels while homogeneity and ductility were superior and approached those of killed steel. Method of pouring, rate of filling of moulds and mould shape have marked effects on quality. With 350–400 g/t (for 0·08% C) and 150–200 g/t (for 0·20% C) added to top-poured moulds at the end of filling the yield of good slabs increased to 90%. Bottle top moulds decreased the amount of Al needed, though the shape is less convenient. Using Si (up to 0·9–1·2%) the 0·20% C steel showed honeycomb structure close to the ingot surface and less ductility in the cold-rolled condition. For this steel the Si must therefore be reduced and the Al used must be increased.—R. S.

Optimum Temperature Conditions for Producing Rimming Steel from Phosphoric Pig Iron. A. S. Kharitonov, M. T. Bul'skii, A. G. Alimov, G. M. Glinkov, and M. Sh. Beloglovskii. (*Stal'*, 1958, (8), 706–709). The ratio Mn/C in the finished steel must not exceed 2·7. Details of the effects of rate of addition during refining and of rate of temperature size are given.

Improving the Structure of the Top of Rimming Steel Ingots. A. M. Uzienko, I. A. Tkachenko, A. P. Varshavskii, E. I. Rabinovich, B. I. Zayakin, and N. G. Zarzhitskaya. (*Stal'*, 1958, (10), 899–905). A marked improvement of low-carbon steel ingot tops can be obtained by prolonging rimming period in the mould which reduces pipe depth and central porosity, improves distribution of segregates and also the ductile properties of the axial zone of the ingot top. The use of 0·15–0·2 kg/t of 45% Fe–Si is the best method of deoxidizing. A continuous boil and additions of micro-granite and the use of Fe–Si for killing reduced top discard by 3–5%.—R. S.

The Relationship between the Order in Which Alloying Additions Are Made to Steel Containing Aluminium and the Steel Quality. A. K. Petrov, V. K. Petrov, and E. D. Mokhir. (*Stal'*, 1958, (8), 742–744). The effect of the addition of Al, V and other elements on gas saturation and crystallization of Al-alloyed steels is much influenced by the order in which they are added, and has a marked effect on the occurrence of defects. Optimum practice is described.

Mass Production of Semi-killed Steel for Mine Supports. V. V. Leporskii, S. S. Petrov, V. M. Presnyakov, and I. G. Kazantsev. (*Stal'*, 1958, (8), 702–706). Use of semi-killed Si-free steel with ~ 1% Mn reduced bloom cropping and increased yield. Deoxidation is with blast-furnace Fe–Mn in the furnace and with 30 kg/t Al in the ladle. No Fe–Si is used. It was rolled under the same conditions as killed steel.

Production and Properties of Non-Ageing Sheet Steel Killed with Aluminium. D. A. Litvinenko, A. I. Marinov, V. K. Barzii, and V. I. Yakushin. (*Stal'*, 1958, (10), 931–938). For automobile sheets of stamping quality, cold-rolled low-C steel is used in which mechanical ageing is locally secured by additions of V or Al. Al is the more economical. The introduction of Al into low-C rimming steel to produce not less than 0·02% residual Al in the finished steel greatly increases the resistance to ageing.—R. S.

Antipiping Compounds and Neck Cores for Steel Casting. K. Beckius. (*Gjuteriet*, 1958, **48**, Sept., 127–145). Ten antipiping compounds, insulating and exothermic, were used in trials, being classified according to C and Al contents. A second section deals with the manufacture and use of neck cores.

Continuous Casting and its Problems. G. Wilz and M. Petitdidier. (**Rev. Mét.*, 1958, **55**, May, 486–494). After briefly discussing existing continuous casting installations including that at Dinain, the advantages and problems of the process are considered. A formula is developed for calculating the economic benefit of continuous casting.—A. G.

Continuous Casting of Ingots of Special Steels. G. Grenier. (*J. Four. Elect.*, 1958, May-June, 98–100). A list of installations and general outlines of the processes are given.

Experiments on the Increase of Absorptive Capacity of Ingot Moulds in the Continuous Casting of Steel. K. G. Speith and A. Bungeroth. (*Forsch. Wirts. Nordrhein-Westfalen*, 1956, No. 234, pp. 15). The effects of the angle of taper of the mould are examined.

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Note.—The continuous casting plant referred to is to be built at the Stalin Iron and Steel Works at Stalino in the Donbass and not at the Kuznetsk Stalin Iron and Steel Works in Stalinsk as stated in the abstract.

Trials with a New Exothermic Lateral Feeder for Reducing Top Discard. A. Theis and K. Nitschke. (*Stahl Eisen*, 1958, **78**, Oct. 2, 1380–1383). Trials for reducing the top discard of 18 : 8 stainless steels with and without Ti additions showed that a reduction of about 50% could be achieved with a specially designed conical feeder head about 6 in. high in which the exothermic powder was pressed into the lining of the cone. However, the addition of exothermic powder to the pool of molten metal was still required. The expense for this treatment is justified only for high-quality steel.—T. G.

Longitudinal Panel Cracking in Ingots. S. C. Desai. (*JISI*, 1959, **191**, Mar., 250–256). [This issue].

Sub-Surface Blowhole Formation in Steel Castings. J. Přibyl. (*Giesseretechn.*, 1958, **4**, Sept., 216–222). The problems associated with subcutaneous and surface blowholes in steel castings are discussed in relation to Czechoslovakian practice; the principal theories of the mechanism of their formation are described and discussed.

Defects in Steel: a Tentative Theory. T. F. Pearson. (*JISI*, **191**, Mar., 219–231). [This issue].

FOUNDRY PRACTICE

The French Foundry Industry. (*Mét. Constr. Mécan.*, 1958, **90**, June, 467–470). A report of a lecture on the French foundry industry, giving an outline of the range of products manufactured, some production data, and a description of the French foundry export market.

Regional Trade Exhibition of Foundry Technique. H. Kühne. (*Giessereitechn.*, 1958, **4**, June, 132–134). The scope of regional trade exhibitions of foundry techniques now being organized in Eastern Germany is outlined, emphasis being laid on the advisability of specializing to some extent on modern processes, such as the CO_2 process and shell moulding.

Future Progress in the Fusion of Metals. F. Hudson. (*Fonderie Belge*, 1958, Apr., 113–116). A brief outline is given of certain factors to be stressed in view of increasing quality demands; improvements in melting techniques and the design and properties of the castings are discussed.

Simple Aids to Transportation in the Foundry. W. Riege. (*Giesserei*, 1958, **45**, Jan. 2, 23–25). Several simple devices are described and illustrated which assist in transporting material in the foundry. These include: a simple 2-wheel carriage for scissor ladles, a casting ladle support, a double loop chain, supporting plates for the sides of a wheel-barrow, a carriage for containers or pallets, a wheel-barrow with a flap near the handles for easy unloading, a hand scraper and shaking chute and finally a tilting apparatus for rolling barrels.—R. J. W.

Mechanization of a Grey Cast Iron Foundry. H. Krause. (*Giessereitechn.*, 1958, **4**, July, 145–153). A detailed account of the mechanization of an East German grey iron foundry is given, and the advantages obtained are discussed.

Cupola with Pre-heated Blast. C. D. Brosch. (*Bol. A.B.M.*, 1958, **14**, Apr., 189–198). [In Portuguese]. The author has designed and built a hot-blast cupola and gives a resume of the calculations for the design of the heat exchanger. The 32 in. dia. cupola produces about 3600 kg iron/h at about 1500° C and uses 12% coke and about 3000 m³ of air/h. The blast temperature reaches 300° C in 40 min and stays at this during the run, rising, with the last charge, to 370° C.—P. S.

The Duplex "Reverberatory Cupola Furnace." C. Gailly. (*Usine Nouvelle*, 1958, **14**, Aug. 7, 27). An account of the design as used in the U.S.A. with an estimate of costs for France.

The Determination of Blast Volume in Cupola Melts. H. Jungbluth. (*Giesserei Tech. Wiss.*, 1958, Sept., 1199–1206). Two methods of calculating the blast volume are developed, and the results of data obtained by both methods compared. The volume of blast consumed is higher according to the results calculated from waste gas analyses than when calculated from the charge and runner analyses. (14 refs.).

Cupolas with Pre-Heated Blast. S. Hájek. (*Hutník*, 1958, **8**, (2), 55–59). [In Czech]. The development and performance of cupolas with pre-heated blast are discussed. The desirability of pre-heated blast is beyond dispute; recent Czechoslovak experience is soon expected to contribute to the fuller understanding of the process.—P. F.

Innovations in Cast Iron Melting. The Hot Blast Cupola. D. Iturrioz. (*Met. Elect.*, 1957, **21**, Nov., 53–62; Dec., 54–64; 1958, **22**, Jan., 229–237; Feb., 57–65). [In Spanish]. The first part of this article refers to the adaptation of cold blast cupolas and reviews the results of trials and various types of installations. In the second part, a schematic diagram of a complete hot blast cupola installation is given. The need to maintain a constant blast temperature and its relation to dust removal is discussed; methods of gas cleaning are reviewed. The third part deals with prolongation of the working life of the lining, particularly by the use of water-cooled iron instead of refractory. Finally the need for a regular slag level, hence tapping control, is examined. Various slag-metal syphons, no-hearth cupolas and the characteristics, advantages and disadvantages of continuous tapping are described.—P. S.

The Significance of the Basic Lined Hot Blast Cupola. F. Varga. (*Koh. Lapok*, 1957, **12**, Jan.-Feb., 24–30). A comprehensive review is given of the practice and metallurgical and economical advantages of the basic-lined hot-blast cupola in O.H. steel production.

Canadian Hot-Blast Water-Cooled Cupola. J. E. Rehder. (*Found. Trade J.*, 1958, **104**, Feb. 6, 143–146). An account is given of the design and operation of a hot-blast water-cooled cupola recently installed in the National Iron division plant of Canadian Iron Foundries Ltd. The operating advantages claimed over a conventional cupola include flexibility with regard to raw materials, economies in refractory maintenance, better control of iron composition, higher melting rates, lower coke consumption and decreased melting losses.—B. C. W.

Experiences with the Basic-Lined Cupola. F. Varga, L. Kálmán and R. Sima. (*Koh. Lapok.*, 1957, **12**, Oct., Öntöde, 204–207). The normal melting of grey iron in the basic-lined cupola furnace results in about 22% decrease in S content. A further decrease may be expected by the use of hot blast. The method is suggested for ingot-mould production.—P. K.

Basic Melting in the Cupola without Lining. L. Kálmán. (*Koh. Lapok.*, 1957, **12**, Jan.-Feb., 30–31). German experiments with pig iron production in cupola furnace without lining are reviewed.—P. K.

Charging Mechanism for Two Cupolas. (*J. d'Inf. Techn. des Ind. Fonderie*, 1957, Oct., 1–6). In the course of mechanizing a foundry

the minimum casting time is given, i.e.

Cast Epoxy Cone Driers for Dielectric steel making process were other variables

casting grey and malleable iron, a single charging mechanism for two cupolas was installed. A description of this installation is given.—R. P.

Buyers Get Better Castings. (*Steel*, 1958, **142**, Feb. 17, 144–146). The advantages of hot-blast cupola melting are described. In the plant concerned, a 450° F preheat is obtained in a 7000 ft³/min, gas-fired unit. Advantages include: improved operating conditions, (less bridging, cleaner tuyeres, higher capacity, more flexibility, lower coke rate, higher iron temperatures); improved quality (better control of composition, less chilled edges, lower sulphur); wider applications (thinner walls can be poured).—D. L. C. P.

Desulphurization in the Furnace with Soda Ash. E. Balzarini. (*Fonderia*, 1958, **7**, Apr., 152–154). The author describes his experiences in desulphurizing iron in a small cupola by means of soda ash. A number of test casts are described in some detail and the results discussed.—M. D. J. B.

The Importance of Slag Control in Iron Foundries. E. Chapo. (*Koh. Lapok*, 1957, **12**, Nov.-Dec., Öntöde, 237–243). The author deals with the composition, characteristics and role of slag in cupola practice. It is sufficient to keep the SiO_2 and FeO content in the slag, as the former indicates the $CaO{:}SiO_2$ ratio and fluidity, and the latter shows the degree of oxidation.—P. K.

A New Electric Steel Foundry in Switzerland. (*J. Four Elect.*, 1957, July-Aug., 137–139). The equipment used in a new electric steelmaking plant is described. Two 20-t tilting hydraulic arc furnaces are in operation. 7000 kVA transformers are used, able to withstand an overload of 20% for 2 h. Electrodes are regulated automatically.—R. P.

Conditions for the Melting of Pure Iron. L. von Bogdandy, R. Schmolke and G. Winzer. (*Arch. Eisenhütt*, 1958, **29**, Apr., 231–235). It was shown by means of experiments using materials normally employed for crucible manufacture—MgO, CaO, Al_2O_3, ZrO_2 and dolomite, and iron containing not more than 0·002% C and O, that, given a suitable pretreatment of the crucible material, not more than $1{\cdot}5 \times 10^{-4}$ g per h of O_2 per cm² of surface contact between crucible and iron was taken up. Hence the choice of crucible material for melting pure iron in a vacuum need not take this factor into account. The report is discussed.

The Manufacture of Steel for Castings in the Electric Arc Furnace. G. Violi. (*Fonderia, Ital.*, 1958, **7**, Feb., 43–52; Apr., 118–128). This article deals with the development of the electric arc furnace for steelmaking, and the construction, lining and electrical characteristics of modern arc furnaces. Part II of the paper discusses raw materials, melting techniques, refining, decarburation with oxygen and refining by means of reducing slags. The author also compares the electric acid and basic processes. (26 references).

Induction Furnaces for Ferrous Alloys in Italy and Abroad. E. Calamari. (*Fonderia Ital.*, 1958, **7**, Apr., 129–133). A brief review is given of the various types of high frequency, medium frequency and low frequency electric furnaces, their relative merits and scope.

Improving Electric Furnace Refractory Life By Special Shell Cooling Techniques. V. J. Howard. (*Mod. Castings*, 1958, **33**, Feb., 68–70). A cooling system used on a 2-t electric arc furnace is described and the advantages derived are briefly summarized.—B. C. W.

Graphite Resistor Furnaces. A. Szulyovszky. (*Koh. Lapok*, 1957, **12**, Apr.-May, Öntöde, 98–101). Reference is made to various kinds of graphite resistor furnaces, used in foundries for melting alloy-steel and metal scrap.—P. K.

Efficiency of the Graphite Rod and Power Consumption of a Graphite-Rod Furnace of 300-kg. Capacity. K. Wagner. (*Giesserei*, 1958, **45**, Mar. 27, 173–175). The power taken up by a graphite rod for heating a melting furnace for iron is almost constant during a heat and the power consumption per month almost proportional to the quantity of iron melted down, although there is a slight decrease in specific consumption if full use is made of the melting capacity of the furnace for each heat.—T. G.

Roundup of Ductile Iron Technology. D. Matter. (*Mod. Castings*, 1958, **33**, Mar., 24–27). The microstructure, properties and heat-treatment of nodular cast irons are outlined together with the problems that arise in melting and casting. The applications of nodular iron are illustrated and described.

Non-Magnetic Cast Iron. Z. Tyszko. (*Fond. Belge*, 1958, **28**, Mar., 94–95). This is a summary of a paper presented by the above author at the 30th Congres de l'ATF at Paris, in June 1957. The properties of ferritic high-Al non-magnetic cast irons are discussed and tabulated.—L. D. B.

Some Properties of Titanium Cast Irons. Á. Mocsy. (*Koh. Lapok*, 1957, **12**, June, Öntöde, 121–129). Starting with ordinary cast iron, an addition of 0·1–0·2% Ti in general increases the strength. This effect is most marked starting with weaker cast irons. With ordinary cast irons of greater strength, it is necessary to add Cr as well as Ti to increase the strength further.—P. K.

Nodular Cast Iron. H. A. Hocking. (*Maschinenwelt Elektrotechn.*, 1958, **13**, Mar., 83–86; Apr., 140–142). An outline is given of the manufacture and properties of nodular cast iron. The properties and applications of nodular cast iron are then summarized briefly.

Correlation of Green Strength, Dry Strength and Mould Hardness of Moulding Sands. R. W. Heine, E. H. King and J. S. Schumacher. (*Mod. Castings*, 1958, **33**, Mar., 49–58). Detailed results are given to show the relationships between green compressive strength, dry compressive strength, moisture, clay type and amount, and the mould hardness developed by moulding. Data are first given for an iron foundry sand, and then for a silica sand bonded with either western bentonite, southern bentonite or fire-clay. All the mixtures gave the same range of green strength, dry strength and mould hardness, so that any clay type can give similar results if the moisture and clay contents and the ramming of the sand are adjusted properly. The application of the results to sand moulding practice is considered.—B. C. W.

Density of Sand Grain Fractions of the AFS Sieve Analysis. R. W. Heine and T. W. Seaton. (*Mod. Castings*, 1958, **33**, Feb., 62–67). Results are given to show the effects of ramming, jolting and vibrating on the density of the various sieve fractions obtained in carrying out the AFS sieve analysis. Five different clay-free silica sands were used and it was found that the density of the fractions increased as the fineness decreased regardless of the method of compaction. However, higher densities could be achieved by vibrating than by jolting or ramming. The relationship between compacting energy and density was the same for all fractions but as the fineness of the fraction increased the maximum density was achieved with less energy. After the maximum density was reached further application of energy decreased the density.

Flow of Molding Sand in a Standard Testing Tube. T. Yoshihara and K. Hashimoto. (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1957, **6**, Feb., 89–92). [In Japanese]. Coloured and uncoloured sands were rammed in alternate layers into a standard tube and sections were cut through the axis to observe flow and the effects of ramming. Effects of grain size and uniformity were noted and factors leading to uniform packing are derived.

The Theoretical Concepts of the Packing of Small Particles. J. B. Caine and C. E. McQuiston. (*Mod. Castings*, 1958, **33**, Feb., 58–61). The laws governing the compacting of uniform and non-uniform particles are discussed with particular reference to the density that can be achieved in foundry sands.

Moulding-Sand Hot-Strength and Its Relation to Defects in Castings. H. W. Dietert, V. M. Rowell and A. L. Graham. (*Giesserei*, 1958, **45**, Mar. 27, 157–166). Mould metal reactions are briefly discussed and the instruments for measuring the hot strength of sands described. The properties of sands at elevated temperatures are discussed with respect to the various surface defects observed on castings.

Ageing of Core Sands Containing Dextrins. Analysis of Dextrins. C. Konlein. (*Fond. Belge*, 1958, **28**, Jan., 19–21). A summary of a paper presented to the 30th Congress of the Association Technique de Fonderie in Paris, June 1957. The changes which take place on hydrolysis of a dextrin have been followed by measurements of optical properties and solubility and the significance of these changes in relation to the ageing of core sands is discussed. Particular attention is paid to the effects on the "blowability index" of the core sands.—B. C. W.

The Costs of Sand Drying. E. Schneider. (*Giesserei*, 1958, **45**, Mar. 27, 167–168). The author discusses the costs of sand drying either in the foundry itself or by the sand producer. He advocates strongly the purchase of dried sand as the freight of dried sand is less and automatic handling very much easier. The cost of drying is analysed.—T. G.

Qualitative and Quantitative Determination of Clays in Foundry Sands by Means of Thermal Analysis. C. Pelhan. (*Fonderia Ital.*, 1958, **7**, Jan., 13–18). [In Italian]. The influence of clays, defined as particles smaller than 20μ, on foundry sands is discussed as well as their effect on cohesion, permeability and refractoriness. The methodology of clay determination is described. Technical and statistical data are given.—M. D. J. B.

Basic Moulding Materials in Steel Foundries. T. Nyizsnyánszky. (*Koh. Lapok*, 1957, **8**, Nov.-Dec., Öntöde, 225–229). The production, properties and use of basic moulding materials in the steel foundry in Diósgyor, Hungary are discussed. The material is made from 50–70% magnesite brick grog, 50–30% fine grain calcined chrome ore, and a binder of bentonite and molasses.—P. K.

Mould Surface Behaviour. D. Roberts and E. E. Woodliff. (*Mod. Castings*, 1958, **33**, 64–70). A simple instrument developed to measure the expansion of rammed mould or core sands in contact with molten metal is described together with the testing procedure used. Results are presented to show the effects of variables such as pouring temperature and sand additives on sand expansion and the occurrence of expansion defects. Using this test it has been possible to set up control limits for sand expansion.—B. C. W.

Experiments with Metal-Sprayed Wooden Patterns. L. Hajdu. (*Koh. Lapok*, 1957, **12**, Apr.-May, Öntöde, 88–90). Hungarian experiments with Al-sprayed wooden patterns are reported. The technique of this method and its economic advantages are discussed in detail.

Good Practices With Better Refractories for Best Ladle Lining. J. H. Rickey jun. (*Mod. Castings*, 1958, **33**, Mar., 35–38, 120–121). The lining of various types of foundry ladles is discussed with particular reference to the ramming of monolithic linings, the construction and use of a ladle form being described in detail. The need for care in drying out ladles is stressed.—B. C. W.

Calculation of the Feeder-Casting Runner in Sand Castings. The Neck of the Feeder. R. Namur. (*Fond. Belge*, 1958, **28**, Jan., 8–12, 29; Feb., 52–57). The correct choice of dimensions for the runner between a feeder head and a casting is discussed, and four different relative positions of feeder and casting are considered in detail. It is suggested that if a and b are the minimum transverse dimensions of the runner, C is the distance between feeder and casting, and D is the diameter of the feeder head, then to obtain satisfactory feeding the following conditions must be satisfied (i) $D/9 > C < D/6$ and (ii) $a = D/\alpha$ and $b = D/\beta$ where $\alpha + \beta < 6$.

Systems of Gates and Risers. S. Kalman. (*Koh. Lapok*, 1957, **12**, June, Öntöde, 129–134). A comprehensive review is given of the various principles and theories for designing an adequate system of gates and risers.—P. K.

Gating Systems for Casting Grey Iron and Brass into Metal Moulds. A. Šustek and J. Vaculik. (*Slevarenstvi*, 1958, **6**, March, Öntöde, 35–39). A method of calculating

the minimum casting time is given, i.e. the time from the start of pouring to the moment at which the metal will no longer continue to flow (zero flow point). Hence it is possible to calculate a coefficient, k, which represents the calorific relationship between the metal being poured and the metal mould at the commencement of casting. The cross-sectional area of the bottom gate may then be calculated, as fully elaborated, from the equation $F_z = \frac{k \times F}{\mu \sqrt{H}}$, where F_z is the cross-section of the bottom gate, F is the surface area of the casting in contact with the metal mould, H is the pouring height, and μ is the coefficient of the hydraulic resistance of the mould. The latter is calculated from the relative thickness of the casting. The calculations are based on a theoretical and practical examination of the conditions governing the thermal exchange between the casting and the mould and the hydraulic conditions of mould filling. It must be calculated for each metal and for each set of thermal conditions at the time of casting.—M. T.

Economy of Material by the Use of Pressure and Spherical Risers. K. H. Meinecke. (*Giessereitechn*, 1958, **4**, Mar. 49–53). Developments and modifications of these risers at the authors works are discussed.

Application of Risers with High Atmospheric Pressure. W. P. Desnizki. (*Iron Steel*, 1958, **31**, Feb., 51–52). The author describes a technique for the improved feeding of castings in which compressed air is applied to the surface of the river, and quotes examples of its use at the Newski-Lenin works in Lenningrad. Details are given of the examination of a test casting made to check the efficiency of the process.—G. F.

Risering of Grey Iron Castings. J. F. Wallace and E. B. Evans. (*Mod. Castings*, 1958, **33**, Mar., 39–45). Previous work on the risering of grey iron castings is critically reviewed and analysed. A procedure for determining the size of risers is presented, and recommendations are made for the design of the riser neck. In conclusion the principles to be followed in locating risers on grey iron castings are outlined. (35 references).—B. C. W.

The Use of Separation Cores in Steel Casting. F. Dubielzig. (*Giessereitechn.*, 1958, **4**, Mar., 62–64). The use of separation cores in East German foundries is discussed, the article being illustrated by several photographs. Advantages of the use of the cores, suitable dimensions and precautions to be taken in their use are among the topic dealt with.

The Problem of Using Metallic Chills in Steel Casting. H. Wesner and W. Probst. (*Giessereitechnik*, 1958, **4**, Feb., 30–32). The use of cast iron cooling pins in the manufacture of certain steel castings led to the appearance of cavities, which were avoided by substituting steel pins. The causes of the defect are discussed.—L. D. H.

Using Cement-Bonded Sand. J. Eckert. (*Castings*, 1958, **4**, Jan., 23–24). The use, reclamation and advantages of cement-bonded sand are very briefly described.

A Critical Examination of the Advantages of the CO_2 Process. J. E. O. Little. (*Fond. Belge*, 1958, **28**, Jan., 18–19). A summary of a paper presented to the 30th Congress of the Association Technique de Fonderie in Paris, June 1957. The advantages and the disadvantages of the CO_2 process are stated and the economic aspects briefly considered.—B. C. W.

Investigation of the Hardening of Sodium Silicate Bonded Sand. C. E. Wulff. (*Mod. Castings*, 1958, **33**, Mar., 81–85). The results of experiments designed to study the hardening produced with sodium silicate-bonded sands by reaction with CO_2, by atmospheric ageing and by heating, are described. Hardening by CO_2 and by evaporation, although achieved by different mechanisms, appears to be similar. Thermal hardening is different, but in the low temperature range it is still reversible. Prolonged CO_2 gassing offers no advantage and atmospheric ageing is recommended for economic reasons. Thermal hardening can however produce high strength at moderate binder percentages.—B. C. W.

Cast Epoxy Core Driers for Dielectric Ovens. J. M. Leaman, and P. L. Morrison. (*Foundry*, 1958, **86**, Mar., 84–87). A discussion is given of the cost, fabrication, and advantages of cast epoxy resin core driers for use in dielectric ovens with contoured sand cores.—B. C. W.

Some Considerations Relating to Laboratory Tests on the Compression of Core Binders. Z. Juhász. (*Koh. Lapok*, 1957, **12**, Apr.-May, Öntöde, 77–81). The compression of a mixture, containing 95% moulding sand and 5% bentonite, in a cast iron shell with polished inner surface, is suggested. The specific sand surface must be reported on the test certificate.

A Mould Drier of Open Construction. (*Giesserei*, 1958, **45**, Feb 27, 126). A mould drier is described, for hot blast from 200–700°, working with a low gas consumption. It is simple in construction and safe to operate. Details are given of the drying of a large sand mould.—L. D. H.

CO_2 Process Useful in Producing Experimental Castings. R. L. Fehr and R. C. Harris. (*Foundry*, 1958, **86**, Mar., 80–82). The method used to produce castings of an experimental rigid fuze body is described, with particular reference to the way in which the complex coring problem was solved.—B. C. W.

Investment Castings Go Civilian. (*Steel*, 1958, **142**, Mar. 3, 95–98). A general review of the advantages of the process with illustrations of typical products.

Some Problems of Using the Exothermic Mixture "Silex" in Steel Foundries. G. Szy. (*Koh. Lapok*, 1957, **12**, Nov.-Dec., Öntöde, 230–234). The production, properties and use of the exothermic mixture "Silex" are described. This mixture contains 30% Fe–Al alloy, of 65% Al content, in powder form, 55% ground scale and 15% fine moulding sand.—P.K.

Producing Castings for Vitreous Enamelling. C. A. Sanders and R. E. Wilke. (*Mod. Castings*, 1958, **33**, Feb., 35–38). The moulding sands, melting practice and metal composition necessary for the production of high quality enamelware castings are discussed.—B. C. W.

Design of Castings with Regard to Fettling Operations. A. Östberg. (*Gjuteriet*, 1958, **48**, Apr., 56–59). Questions of casting design are discussed, with reference to easy removal of cores, gates and risers, and facilitation of subsequent cleaning and grinding operations.

Manufacture of Large Castings for Heavy Machinery in the Soviet Union. P. F. Wassilewski. (*Giesserei*, 1958, **45**, Apr. 10, 193–197). The author discusses Russian practice in the production of heavy castings for such fields as the iron and steel and petroleum industries. The use of sodium silicate and CO_2 for hardening the mixtures, and the employment of special sand compositions is outlined with examples of the manufacture of thin walled castings, including those of high-alloy steel. The handling and subsequent treatment of the castings receives special attention.—L. D. H.

New Special Methods of Preparation of Castings. V. M. Plyatskii. (*Vestnik Machin.*, 1955, (3), 59–64). A review of modern casting methods: continuous casting, vacuum casting, crystallization under piston pressure and pressing of liquid metal and apparatus and methods are described in detail.—S. I. T.

The Canadian Picture on Pipe, Tubing and Casing. D. A. Adamson. (*Can. Min. Met. Bull.*, 1958, **51**, Feb., 102–107). The history of pipe production in Canada is sketched and the firms now producing it are listed. 22 varieties with further subdivisions are listed and briefly reviewed with notes on methods of production and uses with notes on probable future demands.

Investigations for the Choice of Steel for Centrifugal Casting Moulds and Hot Working Tools. J. Klärding. (*Metall*, 1958, **12**, Jan., 12–20). The effect of cyclic temperature fluctuations on steels for hot working tools and moulds is discussed with reference to the author's and other investigations. The steels comprised straight carbon, Cr–Mo, Cr–V, Cr–Mo–V, Cr–Ni, and Mn alloy steels in addition to composition, grain size and the; steel making process were other variables investigated.—J. G. W.

Sodium Silicate Bonded Shell Moulds. P. J. Ahearn and G. I. Gartner. (*Foundry*, 1958, **86**, Feb., 98–101). The results of an investigation into the possibility of using water-glass as a substitute for resin in the manufacture of shell moulds are given, together with a brief description of a machine developed for spraying the wet sand. The reasons for choosing a waterglass with a high SiO_2/Na_2O ratio are outlined, and data are presented to show the effects of moisture content and spraying conditions on sand strength. Satisfactory casts were produced in silicate-bonded shell moulds but further work is necessary to improve the technique.—B. C. W.

Profitable Companions: Shell Cores and Green Sand Moulds. F. K. Shallenberger. (*Mod. Castings*, 1958, **33**, Mar., 32–33). The advantages of shell cores are summarized and their production briefly described.—B. C. W.

Evaluation of Shell Moulding Process Capability. W. C. Truckenmiller, C. R. Baker, and G. H. Bascom. (*Mod. Castings*, 1958, **33**, 71–76). Procedures for establishing the tolerances attainable with shell moulded castings are described by reference to several examples. These include the dimensional control of an automatic transmission part, the development of pattern dimensions for the shell moulding of a split differential casting and the dimensional control attainable with two types of blown shell cores.—B. C. W.

Shell Molds Add to Steel's Uses. (*Steel*, 1958, Feb. 24, 70–71). Shell moulding produces smooth surfaced accurately dimensioned castings. Some specific applications are described.—A. G.

Considerations Relating to the Theory of Shell Moulding. A. Braybrook and B. H. C. Waters. (*Giesserei*, 1958, **45**, May 8, 263–278). This paper gives a detailed review, followed by a discussion, of various aspects of shell moulding, including the factors governing the hot and cold strength of the shell, the grades of sand used, properties of the shell, characteristics of the cast product, and various points relating to design.—L. D. H.

High Strength: Weight Ratio in Aircraft Parts. J. F. Moore. (*Precision Met. Mold.*, 1957, **15**, Apr., 31–33). Investment casting of steel parts and the uses of mercury patterns, shell moulds and powder metallurgical methods are noted.

Bibliography of Publications on Defects in Castings. M. Tordeux. (*Commission Internationale des Défauts de Fonderie*, 1957. Cyclostyled, in 5 parts, pp. 204). With indexes in English, French and German.

The Development of Thick-Walled Steel Castings to Meet High-Strength Requirements. H. Bühler. (*Giesserei*, 1958, **45**, Feb. 13, 87–92). For heavy high-duty steel castings, with wall thicknesses of up to 600 mm, new steels have been developed, characterized by comparatively low carbon contents, and in which most or all of the Ni has been replaced by Cr. A comparison of the mechanical properties, particularly the resistance to impact, indicates that these steels are practically equivalent to the older, high-Ni types. Special heat treatments are necessary, but these have been shown to be economical. Some of these steels have good properties at elevated temperatures.—L. D.H.

Influence of the Chemical Composition of Cast Steel on Hot-Tearing Tendency. III. S. Oki. (*Tetsu-to Hagane*, 1958, **44**, Jan., 15–21). [In Japanese]. Ti has little effect on the hot-tearing tendency of low-sulphur steel, but increases resistance to tearing in high-sulphur steel; it is more economical to use it with Al. The adverse effects of Sn, As, Sb and Bi are assessed quantitatively. Pb, O, H and N have little effect on hot-tearing tendency.—K. E. J.

Design Characteristics of Magnetic Steel Castings. (*Mech. Eng.*, 1958, **80**, April, 64–66). The use of Dynamo cast steel, having properties similar to Armco iron, is recommended where costs and design favour castings. Properties and foundry practice are described.—A. G.

Surface Finish of Manganese Steel Castings. D. Morrell and S. Cross. (*Foseco Foundry Developments*, 1958, April, 11–14). Surface defects are illustrated and a test mould for reproducing the defect was developed. Many surface dressings were tested as reaction with the sand of the mould appeared to be responsible. A proprietary coating supplied in aqueous or alcoholic media is offered to prevent the condition.

Properties of Moulding Materials at High Temperature; IV: Effects of the Sand Grain Size Distribution and Filler on Hot Strength and Deformation of Sand Moulds. K. Futaki and M. Isotani. (*Rep. Gov. Ind. Res. Inst.*, 1958, **7**, Apr., 257–262). [In Japanese]. Hot strength and deformation increase with reduced grain size. When coarse and fine sand grains are mixed, maximum hot strength occurs at 40–60%. Hot strength is increased by silica flour.

Testing and Evaluation of Bonding Materials for Foundry Sands. H. Reininger. (**Giesserei-Praxis*, 1957, **75**, (8), 176–181). The method should correspond to normal full-scale operation and water content, grain size, gas permeability, shear and compressive strengths should be measured.

The Influence of pH Variation in Foundry Moulding-materials on the Surface Finish of Steel Castings. D. H. Houseman. (*Brit. Found.*, 1958, **51**, Mar., 149–155). Previous work on the effects of pH variations on foundry sands is summarized and the results of an investigation into the influence of modifying additions on pH, physical properties and surface finish are presented. Measurements on raw materials and on production sand mixes showed wide variations in pH so that a quality control routine could not be established. Foundry trials of a number of different sand mixes covering the pH range 5–10·5 and involving several different types of castings indicated that there was no improvement or deterioration in surface finish with pH changes in this range.—B. C. W.

Lag Construction of Patterns. "Checker." (*Found. Trade J.*, 1958, **104**, May 8, 547–548). The making of cylindrical patterns with "lags" or staves is briefly described.

Design of Castings with Regard to the Cores. A. Östberg, (*Gjuteriet*, 1958, **48**, Feb., 19–24). A report by the Castings Design Committee of the Sveriges Mekanförbung. Cavities should be designed to facilitate production and insertion of cores. Often a casting should be divided into simpler components to reduce core work. Numerous designs are shown and discussed.

Correct Gating Technique for Medium and Large Castings. W. Göschel. (**Giesserei-technik*, 1957, **3**, July, 160–162). The effect of downgates of circular section in preventing vortex formation and the carrying of dross into the casting, and the alleged deficiencies of rectangular downgates are discussed. Keeping the gate closed until the sump is full, the desirability of pouring from the short end into the sump, the proportions of the skimming channel and an unfamiliar design which has been found satisfactory are then described.

An Investigation of the Flow of Foundry Alloys with Various Gating Systems Used in Sand Mouldings. M. Jeancolas. (*Brit. Found.*, 1958, **51**, Mar., 119–127). Preliminary results on the flow of various foundry alloys through different types of gating systems are presented. It is concluded that at temperatures well above the liquidus the majority of foundry alloys flow in practically the same manner through a given gating system. With systems of small dimensions comprising a large number of gates, those systems which are under pressure give the best distribution from the point of view of equilibrium between the flow and the gates.

Some Requirements for Successful Fluidity Testing. S. A. Prussin and G. R. Fitterer. (*Mod. Castings* 1958, **33**, April, 77–84). Variability in test results is ascribed to variation in the velocity of the metal stream entering the fluidity mould and to the mechanism of flow cessation. Data is given for the actual rate of metal flow within the mould.

Design of Castings in Relation to Pouring. A. Ostberg. (*Found. Trade J.*, 1958, **104**, June 26, 773–776). Design of thin sections and the difficulties with large horizontal surfaces are discussed.

The Parlanti Mould Process for the Casting of Metal by Controlled Rate of Heat Transfer. C. A. Parlanti and R. D. Venckiasen. (*Mod. Castings*, 1958, **33**, May, 79–85). The Parlanti process which employs a mould of highly conductive aluminium to control both the direction and rate of heat transfer from the molten metal is described. The mechanics of the system and its applications are discussed.—A. G.

Purchase Specifications for Commonly Used Steel Foundry Mold and Core Sand Binders. E. G. Vogel. (*Mod. Castings*, 1958, **33**, April, 59–62). Tests are described for assessing the qualities of various binder materials, namely bentonite, corn cereal flour, core oil, plastic core binder and cold set oil.—A. G.

The Use of Supports in the Preparation of Cores in the Iron Foundry. (*Fonderia*, 1958, **7**, Mar., 121–125). The use of supports as a means of getting sounder castings by distributing displacements and deformations is discussed. Various types of support are described and illustrated.—M. D. J. B.

Process Controls for Making Turbine Castings. (*Mech. Eng.*, 1958, **80**, April, 61–63). Procedures at the Schenectady Foundry (G.E.C.) are described, which have resulted in stronger high temperature castings and fewer rejects.—A. G.

Investment Casting in Europe. H. J. Marshall. (*Prec. Met. Mold.*, 1958, **16**, June, 24–26). An account of the Plyshell process, with illustrations of products.

Continuous Casting of Tubes. W. Schwarzmaier. (**Stranggiessen-Entwicklung und Anwendung*, 1957, pp. 146–161). A review of patent literature.

Measurement of Mould Hardness and Standardized Test Body. F. Hofmann. (*Giesserei*, 1958, **45**, Jan. 2, 9–13). The experimental method used for measuring hardness is first illustrated and described. The results, relating relative mould hardness to green compression strength are presented graphically. An evaluation of the test results is given and comparisons made. A discussion on whether three or six blows should be made with the ram for a standardized test procedure is backed by experimental results.—R. J. W.

Cast Crankshafts. J. B. Hucke. (*Bol. A.B.M.*, 1958, **14**, Apr., 181–188). [In Portuguese]. The alloys that have been used for this purpose are described and their properties are compared. It is concluded that it is possible to produce satisfactory cast crankshafts economically.—P. S.

The Use of Forsterite in Shell-Moulding. (*Fonderia*, 1958, **7**, May, 229–231). [In Italian]. The properties of forsterite or $2MgO, SiO_2$ are discussed and their effect on shell-moulding is described. Methods of preparation and use are reviewed. Much of the work described was undertaken by The Columbia Steel Casting Co., Oregon.—M. D. J. B.

Influence of Thermal Conductivity on the Behaviour of Iron Castings. J. A. Davis, H. W. Deem, and H. W. Lownie. (*Fonderia*, 1958, **7**, June, 273–275). [In Italian] The authors evaluate the thermal conductivity of a range of cast irons and show how conductivity can affect the quality of the casting and its strength.—M. D. J. B.

The Application of External Cooling to Steel Casting. A. Roth. (*Giesserei*, 1958, **45**, May, 289–295). External cooling is used to achieve more complete saturation of large castings. Examples are given to show what improvements can be achieved in the quality of castings and volume of output.—L. J. L.

Contribution to the Question of the Solidification of Castings. N. G. Girschowitsch. (*Giess. Tech. Wiss.*, 1958, Jan., 1021–1035). The solidification of castings is considered in mathematical terms. The influence of various factors such as an insulating layer, the design of the casting, the super-heat of the melt, and the solidification range are discussed at length. A nomograph is presented for the determination of the solidification time. The determination of the physical constants for the solidification equations are described. Finally, consideration is given to crystallation, from the melt and "flowability." (29 diagrams, 49 references).—R. J. W.

Determination of the Ingate Cross-Sections of Castings Poured in Sand. C. Trenckle. (*Giesserei Tech. Wiss.*, 1958, Sept., 1171–1197). A theoretical treatment dealing with conditions for the determination of casting duration, correction of the application of hydrodynamic laws, frictional losses, lamellar and turbulent flow, flow in the separate parts of the gating system, speed factors for all types of casting, and determination of the pressure in the gating system.

Several Investigations on the Shrinkage of Cast Iron. A. Wittmoser and H. A. Krall. (*Giess. Tech. Wiss.*, 1957, Oct., 975–988). The problem of increased shrinkage gradients in cast iron over the past decade is discussed. The change in cast iron metallurgy over the period 1910 to 1955 is traced. The main change has been to increase the silicon content for a constant carbon content. The effect of this on the shrinkage has been investigated. Several other investigations on shrinkage and the formation and distribution of shrinkage cavities and various factors affecting them are described. (54 references).—R. J. W.

Inverse Chill in Grey Cast Iron. G. T. Brown and R. T. Allsop. (*Brit. Found*, 1958, **51**, May, 251–257). An investigation of inverse chill that occurred in some grey iron castings is reported. The example of inverse chill showed the features of acicular carbide and supercooled-type graphite. The high S : Mn ratio is in this case considered to be responsible for the stabilization of white iron. Existing theories of inverse chill cannot explain all the present observations. These theories are reviewed and discussed.—T. G.

What the Aircraft Maker Wants in a Steel Casting. L. H. McCreery. (*Met. Prog.*, 1958, **74**, July, 71–75). The space available for structural components in future aircraft will be diminished, i.e. fittings of extreme complexity having maximum strength will be required. The solution to this problem is the use of high-integrity, close-tolerance steel castings, heat-treated to strength levels of 180 000 p.s.i. or more, which would require little or no machining. The equipment of a foundry to meet these requirements are discussed and some examples of castings quoted.

The Problem of the Reduction of Silica by Carbon in Iron Melting and its Importance for Cast Iron. W. Oelsen and E. Schürmann. (*Giess. Tech. Wiss.*, 1958, Jan., 989–994). The equilibrium between Mn-bearing molten iron and Fe–Mn silicate in a sand crucible is first discussed. The effect of carbon on the Mn and Si contents of iron melts is also described. The reduction of Si by carbon in strong SiO_2 or silica-bearing slags is followed. Experimental results on the Si–C-isotherms for different temperatures their importance in over-heating a cast iron melt are described.

Statistical Control of Quality in Foundries. R. Sacerdote. (*Fond. Ital.*, 1958, **7**, May, 169–172). [In Italian]. A brief account is given of the usefulness of statistical methods in keeping a check on the quality of foundry products. Frequency charts and tables are reproduced.—M. D. J. B.

A French Glossary for Foundrymen. (*Bulletin B.C.I.R.A.*, 1958, **14**, May, 353–361; July, 416–424; Sept., 492–499). Part I, Abaque to Dureté. Part II. Eau chargée to Oxydation, pellicules de. Part III. Paillasse to Zone fondue, méthode de la.

VACUUM METALLURGY

Vacuum-Induction Melting. F. N. Darmara, J. S. Huntington, and E. S. Machlin. (*JISI*, 1959, **191**, Mar., 266–276). [This issue].

Vacuum Treatment of Steel by the Bochumer Verein Stream Degassing Process. A. Tix, G. Bandel, W. Coupette, and A. Sickbert. (*JISI*, 1959, **191**, Mar., 260–265). [This issue].

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The Heat Treatment of Spheroidal Cast Iron. V. Gottardi. (*Fonderia Ital.*, 1958, **7**, Sept., 331–334). [In Italian]. The author shows that the process of ferritization of an iron with a martensitic matrix is substantially different from that of an iron with a perlitic matrix. He confirms that ferritic iron obtained by heat treatment of a martensitic matrix is susceptible to short heat treatment cycles, e.g. by induction tempering or by flame hardening. (6 references).—M. D. J. B.

The Heat Treatment and Strength Properties of High Manganese Cast Steel. K. Roesch, S. Pramanik, and H. K. Görlich. (*Giesserei Techn. Wiss.*, 1958, Sept., 1207–1215). A systematic investigation of manganese steel, with and without Ni and Cr additions is described. Bending tests showed that toughness increased as the hardening temperature was raised; the results indicated that pure austenite is present only above 1000°. Tempering tests gave a rapid decrease in toughness at temperatures exceeding 300° C due to carbide separation. End quench tests showed that low cooling rates could lead to severe cracking.

Effect of Heating and Cooling on the Mechanical Properties of an Alloy Steel. A. S. Kenneford and T. Williams. (*Proc. Inst. Mech. Eng.*, 1957, **171**, (30), 823–828). En 29 steel was heated above the critical range and cooled. Rapid cooling gave poor mechanical properties down to the martensite temperature of about 300° C. Below this strength and ductility increased. Relations of repeated heating and cooling to crack formation are discussed.

Effect of Heat Treatment on the Microstructure and Low-Temperature Properties of Pressure-Vessel Steels. J. H. Gross, E. H. Kotteamp, and R. D. Stout. (*Weld. J.*, 1958, **37**, Apr., 160s–168s). Methods were developed of simulating with ½ in. plate the cooling rates at the surface and centre of a waterspray cooled 4-in. plate, and the cooling rate of a normalized 4-in. plate. The effects of the heat-treatments on two carbon steels and seven low-alloy steels were determined together with the effects of stress relieving and of 5% tensile prestrain. Tensile and V-notch Charpy tests were carried out after each operation. It was found (*a*) that accelerated cooling could be used to raise the yield and tensile strengths of thick plate, (*b*) notch toughness was only appreciably enhanced in low-alloy steels if stress relieving was employed after cooling, and (*c*) the benefit of accelerated cooling originated principally from the suppression of massive ferrite and the formation of a fine ferrite-carbide aggregate.—B. C. W.

Molten Metals or Alloys as Heat-Treating Media for Steel. A. P. Garashchenko, A. P. Gulyaev and Z. S. Luneva. (*Metallov. Obra. Met.*, 1958, Jan., 21–24). The use of Al and its alloys as substitutes for Pb and salt baths is studied. Al–10% Si was used and suitable coatings for work pieces and tank walls were examined.

The Use of Electricity in Heat Treating Operations at Chrysler. R. E. Morken. (*Met. Treating*, 1958, **9**, May-June, 2–5, 52–53). Types of furnace are indicated and sintering, brazing, furnace atmospheres, induction heating, surface hardening and induction melting are very briefly outlined.

The Gear Wheel in Aeroplane Construction, Able to Support the Greatest Load. H. Brugger. (*V.D.I.Z.* 1958, **100**, (9), 353, 356). With suitable material subjected to proper heat treatment, it is possible to produce gear wheels for aeroplane construction for which the safe permanent load is twice as high as for wheels in lorries which are hardened by the usual means. The article considers the properties of the steel, and its thermal treatment in all stages.—L. B.

The Use of 'Armoured Steel' for the Bearings of Bridges. (*Acier-Stahl-Steel*, 1958, April, 177–178). 'Armoured steel' is ordinary rolled steel given a special hardening treatment which penetrates 15 mm. Considerable reductions in weight and cost are claimed over high tensile steels.—A. G.

Induction Heating. R. O'Donoghue. (*Elect. Rev.*, 1958, **162**, May 16, 909–911). An outline of apparatus and methods for hardening and brazing is given.

High-Temperature Carburizing Takes Half the Time. P. M. Unterweiser. (*Iron Age*, 1958, **181**, May 22, 123–125). Tests at up to 1900° F show that carburizing time can be reduced. Russian work is quoted as well as results on four SAE grades.

The Distribution of Residual Stresses in Carburized Cases, and Their Origin. D. P. Koistinen. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 31, pp. 24). Experimental data obtained support the theory that the origin of the compressive stress in the case lies in the sequence in which transformations occur in the case and in the core. Maximum residual compression is shown to occur at 50–60% of the total case depth.—E. E. W.

Carburizing Compound Handling and Dust Control. A. J. Beck. (*Met. Treating*, 1958, **9**, May-June, 10, 51). A dust booth and equipment at Commercial Steel Treating Corp., Detroit is described.

The Effect of Surface Hardening by Heating with Mains Frequency Currents on the Properties of Working Rolls for Cold Rolling. V. N. Novikov. (**Metallov. Obra. Met.*, 1956, (6), 36–47). A comparison with furnace hardening is reported. Increased hardness and greater uniformity was obtained, greater depth of both hardened and transformation zones, uniformly distributed martensite and reduced austenite with increased durability were shown by the induction hardened rolls.

Flame Hardening and Local Heat Treatment. H. W. Grönegress. (*Rev. Mét.*, 1958, **55**, Mar., 211–217). The use of the Jominy hardenability test to predict the surface hardness and depth of hardening given by flame hardening of carbon and low-alloy steels is described. It is possible without loss of accuracy to replace the specified long-time heating tests by rapid tests using rotating burners. In the case of high-alloy steels the surface hardness can be estimated but not the depth of hardening.—B. G. B.

Flame Heat-Treatment of Rails for Points and Crossings and for Rail Ends. H. Steiger. (**Der Peddinghaus Erfahrungsaustausch*, 1955, (3), 22–26). Earlier trials led to flaking, but the process has now been re-examined. The surface hardness and depth of hardening required are found from the position of maximum stress, and the necessary preheating discussed. Utilization of heat of rolling would be most desirable but was impracticable, with the degree of control available. Heating with a moving flame (in practice a series of flames would be used) was studied with an inserted thermocouple and quenching conditions in relation to composition are discussed, and the avoidance of the need for subsequent tempering. Two methods of hardening are described in detail and the use of an oil emulsion quenching medium or the use of a misting nozzle are recommended.

Induction Hardening of Cast Iron. (*Met. Treating*, 1958, **9**, May-June, 14, 17; from *High Frequency Heating* Review, **1**, (21). A review with illustrations of structure and a table of types of iron, treatments tried, and results, is given.

[Heat Treatment of Rolled Railway Wheels at the Karl Libknekht Works in the Ukraine]. S. I. Belokurov. (*Stal'*, 1958, (5), 468). A long series of experiments on induction heating has just concluded showing great advantages over flame furnace treatment. The grain of the steel does not grow and tensile strength is increased. No scale is formed and no decarburization occurs. The process has been fully automated and 40,000 t/year of wheels are to be treated. No details are given.

Combine Nitriding, Induction Hardening on Low-Alloy Steel. P. M. Unterweiser. (*Iron Age*, 1958, **181**, June 19, 122–124). Treatment of 4340 steel is described giving an increase of hardness from RC57 to RC64 in 2 sec. Structures are shown and nitrided core depths are indicated.

Grain Growth and Surface Decarburization in Induction Heating of Steel Billets. Ya. I. Karker and M. G. Kogan. (*Metallov. Obra. Met.*, 1958, Jan., 46–49). Little change is produced by 2–3 min. at 1100–1200° C. In 5½ min. a somewhat thicker scale is produced and at 1300° C there are signs of overheating. Carbon and alloy steels were used and comparison with an oil-fired furnace was made.

A Study of the Ferritization of Nodular Iron. E. J. Eckel. (*Mod. Castings*, 1958, **33**, April, 85–99). Two nodular irons were subjected to four different types of ferritizing heat treatment. Results are compared on the basis of rate of response, tensile and impact properties.—A. G.

The Heat Treatment of Grey Cast Iron. (*Fonderia*, 1958, **7**, Apr., 169–170). The heat treatment of grey cast iron for the purposes of softening and stress-relieving are described. The temperatures to be used in both cases are given for irons of various compositions.—M. D. J. B.

[Annealing Ball Bearing Steel]. V. F. Isupov. (*Stal'*, 1958, (5), 468). The period of black annealing of rods could be reduced from 46 to 12 h by improving the operation of the furnace by leading part of the waste gases below the charge, by accelerating heating from 50–100° h to as high as 350–400° h, by increasing holding temperature from 790–810° C and by reducing the cooling period for a charge of 9–10 t from 13 to 5 h. Isothermal holding is 1–2 h at 720° C. The period of bright annealing can similarly be reduced from 30 to 12 h, by speeding up, heating and by increasing annealing temperature from 720–730° to 780° C.—R. S.

The Effects of Annealing on the Properties of Steel. R. Sanchez Cuentas. (*First National Congress of the Iron and Steel Industry [Mexico]*, 1955, 161–164). A description of changes in physical and mechanical properties caused by annealing treatments is given.

An Automatic Austempering Plant. R. S. McFall and C. A. McFadden. (*Machinery*, 1958, **93**, July 2, 43–46). The works of International Business Machines Corp., Kingston, N.Y., is described.

Project and Calculations for a Special Furnace for Austenitising Stainless Steel Sheets. I. Montevecchi. (*Met. Ital.*, 1958, **50**, Feb., 53–58). The characteristics of an electric furnace for the heat treatment of stainless steel sheets are studied by calculus methods. The author suggests a method of graphical integration for solving the differential equations. Once the heating conditions are properly determined the leading dimensions of the plant can be correctly assessed. Details are given of the data collected after the plant came into commission and these are compared with the theoretical computations. Drawings are given showing the principal dimensions and characteristics of the plant.

The Influence of Gaseous and Salt Bath Nitriding on the Properties of Structural Steels (Part I). H. Wiegand and M. Koch. (*Metalloberfläche*, 1958, **12**, Mar., 69–74). The article commences with a brief outline of the nitriding process and the formation of the nitride layer. The increased resistance to alternating stresses is then discussed: this is followed by a section dealing with the effect of quenching and tempering at various temperatures on the nitride structure. Photomicrographs show clearly the increase in the size and number of nitride needles with increasing temperature of the heat treatment. (22 references). (Part II). (Apr., 97–101). This deals with the selection of materials, the experimental conditions, and test results on the nitrided products.—L. D. H.

Dependance of Decarburization on Rate of Graphitization in Whiteheart Malleable Iron. C. T. Moore. (*B.C.I.R.A. J. Res. Dev.*, 1957, **7**, Dec., 82–94). The rate of decarburization is decreased when graphitization of eutectic cementite occurs, although the effect is slight in balanced sulphur iron. Excess sulphur irons decarburize more slowly but to a greater depth than balanced sulphur irons. This is believed to be partly due to slower solution of graphite. During the later stages of annealing the solution rate of graphite is believed to control the decarburization process particularly in excess sulphur irons.—B. G. B.

Annealing Tool Steel. J. J. Herwijnen. (*Metalen*, 1958, **13**, Apr. 15, 124–128). The author refers to the need for annealing tool steel and the different methods adopted and points out the dangers of excessive annealing. The restriction of the annealing range is explained when working above the critical temperature with steel of the type 0·5%Cr, 1·2%Mn, 0·9%C, 0·5%W. The difficulties likely to arise when annealing a Cr–4%Ni–Mo tool steel are indicated and a range quickly giving relatively good results is put forward. (10 refs.).—F. R. H.

Confirmation of the Effects of High Temperature Annealing on the Properties of Transformer Sheet. J. Kolofik. (*Hutn. Listy*, 1958, **13**, (3), 241–245). [In Czech]. Pilot plant experiments showed that vacuum annealing of 4%Si transformer steel at 1150° C for several hours led to a reduction of watt losses to about 1 W/kg. By the use of suitable annealing furnaces such low losses should be obtainable in full scale production. Adequate watt-loss reductions by vacuum annealing were also obtained with sheet containing small amounts of Al.—F. F.

Preheating Residual Stresses Stress Relieving. W. Skraragen. (*Weld. J.*, 1958, **37**, Jan, 21s). A report of remarks at the 2nd World Metallurgical Congress, Chicago, Nov. 1957.

Customers Call the Temper. (*Steel*, 1958, Feb. 24, 75). A brief description is given of a new heat treatment installation enabling stainless steel bars to be heat treated and normalized to customers specifications.—A. G.

Heat Treatment of a High Strength Cast Iron with Spheroidal Graphite. T. G. Demidova and M. N. Kunyavskii. (*Vestnik. Machin.*, 1955, (10), 30–34). Castings made of cast iron with spheroidal graphite, especially those with thin walls, results in a mottled structure which requires an additional heat treatment. Details are given of studies of (1) graphitization of the eutectic and secondary cementite in mottled Mg cast iron, (2) spheroidization and graphitization of the eutectoid cementite, and (3) processes of solution of carbon in the γ-phase, transformations of supercooled austenite and the stabilizing thermal treatment. The influence of the temperature of normalization on the hardness of the metal, durability and resistance to wear and other properties are studied.—S. I. T.

The Influence of Silicon on the Heat Treatment of Nodular Graphite Iron. L. Sofroni. (*Acad. Romine Met.*, 1957, **2**, (1–2), 23–36). Mg reduces somewhat and Si reduces considerably the time for graphitization. This increase from 1 to 3·3% Si cuts down the first stage by a factor of 6–8 and the second by 1½–2. Graphitization takes place from the eutectoid cementite practically completely on cooling in the furnace when the temperature of cooling in air is not below 880–900°. The diagram is complicated as there are two kinetic maxima. Raising the Si content leads, as with steel, to the appearance of two ranges of minimum stability for supercooled austenite. Over 2·5% Si hardenability falls and stability to annealing is raised to 550° C. Given the great influence of Si it is advised that malleable iron should be replaced by spheroidal as time of malleabilization is thereby decreased from 60–90 h to 8–12 h. (8 references.)

Thermal Treatment and Strength of Mark IX13 Steel. S. K. Maximov. (*Vestnik Machin.*, 1954, (8), 65–67). [In Russian]. Samples of stainless constructional steel were heated at 860° C for 1 h, cooled in air and then normalized. Samples were quenched in oil and annealed. The study of the structure and the mechanical properties of the samples showed that the optimal temperature of quenching is 1000–1100° C, while the optimum annealing temperature depends on the required properties of the finished product, but the suggested interval is 600–700° C. Detailed accounts of the mechanical properties as relates to the quenching and annealing temperatures are given.—S. I. T.

Quenching and Quenching Media. B. F. Russell. (*Austral. Eng.*, 1958, **50**, 70–80). The theory of quenching is outlined, martensite formation and the hardenability concept and its application are discussed. The stages of quenching and aqueous oil and molten salts as media are briefly reviewed and marquenching is explained. (28 references).

A New Quenchant for Steel. P. E. Cary, E. O. Magnus and W. E. Herring. (*Met. Prog.*, 1958, **73**, Mar., 79–81). Polyvinyl alcohol (15%) in water is shown to be intermediate between water and oil and to harden medium-carbon steel parts without much danger of cracking. A preservative and an antifoaming agent were added.

The Quench-Ageing of Commercial Structural Mild Steels in the Region of Atmospheric Temperature in Different Climates. F. C. Althof and D. Böhm. (*Neue Hütte*, 1958, **3**, Feb., 101–109). Plain carbon structural steels, after normalizing or hardening, were, after a second heat treatment, quenched in water or cooled in air from various temperatures, and the changes in hardness investigated at different ambient temperatures for 400 days. It was concluded that the quench-ageing of these steels was due mainly to supersaturation of the α-iron in carbon. Nitrogen and oxygen have no influence on quench-ageing under the conditions investigated. (17 references.)—L. D. H.

Contribution to the Knowledge of the Quench Ageing of Unalloyed Mild Steels, mainly from Observations of Reversal. M. Nacken and H. Sturies. (*Arch. Eisenhütt.*, 1958, **29**, Apr., 235–240). A series of experiments is described in which the ageing properties and reversal of Thomas steel and high purity iron were investigated by means of damping measurements.

A Contribution to the Improvement of the Technological Process of the Production of [Railway] Tyres by the Resita Metallurgical Combine. R. Meulescu. (*Acad. Romine Met.*, 1957, **2**, (3), 351–360). These were originally formed from separate pear-shaped ingots. They are now made from large ingot sections. Quenching and heat treatment are described.

On the Influence of Tempering of Chromized Parts on Their Durability and Seizing Properties while Working on Steel. D. N. Garkunov and F. N. Naumov. (*Vestnik Machin.*, 1955, (10), 34–37). Two problems are studied: (1) the influence of the temper of the porous chrome plating on its durability and that of the coordinated steel or cast-iron surface, (2) the influence of the temper of smooth or porous chrome plating on the seizing properties while working on steel. The porosity appears to be an important factor in this process. S. I. T.

Effects of Tempering in Liquid and Gaseous Media on the Mechanical Properties of Malleable Cast Iron. Č. Hloušek. (*Slévárenství*, 1958, **6**, (2), 23–30). [In Czech]. The cast iron used contained 2·25–2·49%C, 0·118%Si, 0·38%Mn, 0·1%P, 0·18%S, 0·03–0·04% Cr. It was melted in an electric h.f. furnace and inoculated in the ladle with 0·02%Al. The first graphitization anneal took place either in an electric furnace containing a protective atmosphere or in a salt bath, the temperatures utilized being 1000°, 1050° and 1100° C. A laboratory electric furnace without protective atmosphere was used for the second graphitization. Optimum temperatures for annealing in the salt bath were found to lie in the range 1000–1050° C; over the range 900–1100° C a steady deterioration of the mechanical properties resulted as the temperature increased. Optimum mechanical properties of the temper iron castings were obtained by annealing while gradually cooling from 760° to 720° C, followed by a short isothermal anneal at 800° C. Nodular pearlite present in the structure contributed to the attainment of desirable properties. The heat-treatment without packing of the samples was as effective and shorter than the conventional annealing procedures.—F. F.

Automation in Heating and Quenching. II. N. K. Koebel. (*Ind. Heating*, 1958, **25**, May, 908–916). Equipment for automating the heat treatment of large parts is described.—A. G.

18 Ways to Move Parts in a Furnace. (*Steel*, 1958, **142**, June 23, 90–91). Loading, conveying, and discharging devices employed in automatic heat-treatment are briefly reviewed together with control mechanisms.—A. G.

Carburizing Boxes That Last. (*Wiggin Nickel Alloys*, (49), 21–23). Pack carburizing boxes of Nimonic 75 alloy are described. About 10 000 h service is expected.

Appropriate Depth of Hardening in Surface-hardened Gear Teeth. H. Glanbitz. (*V.D.I.Z.*, 1958, **100**, Feb. 21, 216–226). Findings relating hardness distribution and surface-hardening treatment, with static and dynamic properties of gear teeth are collated. From these and from practical experience it is concluded that the optimal value of the depth of hardening varies with operational requirements. The hardening depths obtainable with different hardening treatments are quoted.—J. G. W.

Surface Hardening of Gears. E. Höhne. (*V.D.I.Z.*, 1958, **100**, Feb. 21, 241–248). Following a summary of the connection between hardness induced by surface treatment and operational needs, the principal hardening methods are described and compared as regards hardness and its distribution. Included are brief descriptions of hardening equipment.—J. G. W.

Investigation of the High Frequency Induction Surface Hardening of Steel. H. Nishimura, S. Yamazaki, S. Tanabe, and Y. Okamoto. (*Suiyokwai-Shi*, 1957, **13**, Dec., 335–340). Steel with 0·45% C was induction-hardened and temperatures of the surface layer in heating and cooling were measured oscillographically. With a fixed coil maximum hardness was attained at 850° C and with a moving coil at 1000° C. Microstructures are described.

Gears with Nitrided Teeth at High Peripheral Speeds. C. G. Wahl. (*V.D.I.Z.*, 1958, **100**, Feb. 21, 252–254). Gears for high-speed, heavy-duty, steam turbines are discussed, and the advantages of hardening, notably nitriding, are weighed.—J. G. W.

Soft Nitriding and Sulfinuz Treatment. Two New Processes for the Treatment of Geared Constructional Elements. J. Müller. (*V.D.I.Z.*, 1958, **100**, Feb. 21, 235–239). The two treatments in question are described and their effects on the structure and properties of the parts treated explained. Their uses for the purpose of increasing wear resistance and fatigue strength are pointed out.—J. G. W.

The Carbonitriding Process. G. Limentani. (*Met. Ital.*, 1958, **13**, May, 191–195). [In Italian]. The advantages of the carbonitriding process are briefly discussed. The process is described with special reference to heat treatment, quenching rate and controlled atmospheres. The problem of residual austenite and the means of reducing it to a minimum are discussed. The behaviour of heat treated carbonitrided steels is compared with that of carburized steels. An automatic carbonitriding furnace is described.—M. D. J. B.

Symposium on Annealing of Low Carbon Steel. G. W. Form and E. B. Evans. (*Ind. Heat*, 1958, **25**, March, 523–538, 626). Summaries are presented of papers on the effect of cold work on present day annealing, ageing, yield and flow phenomena, orientation and anisotrophy in sheet steels, a recirculation steel melting furnace, metallurgical factors in working and cleaning hot-rolled strip, the generation and use of prepared atmospheres, annealing cycles and short time annealing.

Annealing of Ferrous and Nonferrous Alloys in Closed Containers with Controlled Atmospheres. W. Herdieckerhoff. (*Draht*, 1958, **9**, Apr., 141–143). The developments discussed include—forced circulation of atmosphere through the annealing pot and vacuum-annealing pots, with reference to bright annealing and blueing of ferrous and non-ferrous wires.

Hydrogen Supplied to Tube Annealing Furnaces from Efficient Bulk Storage System. (*Ind. Heat.*, 1958, **25**, June, 1 163–1 164). The system at the Superior Tube Co. plant at Norristown, Pa. is briefly described.

Formation of Texture During High Temperature Annealing of Cold Rolled Transformer Steel. G. N. Shubin and L. V. Mironov. (*Stal'*, 1958, (7), 648–650). The following heat treatments are recommended for cold-rolled trans-

former steel: (*a*) to increase the intensity the texture, the steel is heated slowly in the range 900 to 950° C at the rate of 30 to 60° C per hour. This treatment ensures the completion of secondary recrystallization without any special holding period. With heating rates of 100° C/h, step heating must be used and the steel held in the range 925 to 950° C; (*b*) to obtain steel with comparatively low anisotropy of magnetic properties, rapid heating in the annealing process is essential.—R. S.

The Absorption of Nitrogen in Low Carbon Steel Sheets During Process Annealing. T. Ando. (*Toyo Kohan*, 1957, **5**, Dec., 1–22). [In Japanese]. Ammonia as a protective gas is the source of N_2. Urea and biuret are also satisfactory. Tables, graphs, and diagrams are supplied with captions in English.

A Method of Controlled Under-Quenching of Impact Bars. M. R. Meyerson and S. J. Rosenberg. (*Rev. Mét.*, 1958, **55**, Apr., 318–322). A method is described for heat treating impact specimens in order to produce uniform and accurately controlled under-quenched microstructures and hardnesses at the locations where the notches are to be placed. The method is essentially a modified end-quench method. Data is given showing the deleterious effect of under-tempering upon the impact properties of a number of steels. In tempered steels the deleterious effect of under-tempering becomes more pronounced as the under-quench hardness decreases.—B. G. B.

The Metallurgy of Tempering and Annealing in Fractional Minutes. R. K. Wuerfel. (*Ind. Heat.*, 1958, **25**, June, 1128–1130, 1132, 1134, 1136, 1142).

FORGING, STAMPING, DRAWING, AND PRESSING

Forging. P. Enfer. (*Technique Moderne*, 1958, June, 207–216). The author reviews methods and machinery for forging, the heating systems used, lubricants, etc. He then describes the forging operations for some typical parts. Maximum and minimum forging temperatures for carbon steels, alloy and resistant steels as well as for some non-ferrous alloys are given.—R. P.

The Manufacture of One-piece Wheels at the Dunes Plant of the Société des Aciéries et Forges de Firminy. J. Berthelet. (**Technique Moderne*, 1958, June, 53–58). The complete installation and machinery is described. It consists mainly of foundry, forge, rolls and finishing shops. Different types of one-piece wheels and their steel composition and properties are given.—R. P.

The Determination of Power on Horizontal Upsetting Machines and Mechanical Forging Presses. H. Mäkelt. (*V.D.I.Z.*, 1958, **100**, Sept. 21, 1313–1318). Mechanically-driven forging machines are often overloaded, as the upsetting and forging powers are unknown. The measurement of these quantities and the evaluation of the results are discussed.

Structural Requirements for C-Frame Eccentric Presses for Chipless Forming. W. Panknin. (*V.D.I.Z.*, 1958, **100**, Sept. 21, 1287–1293). Details of design and construction to ensure safe and efficient operation are given.

Problems of Sheet Bending. T. Lehmann. (*V.D.I.Z.*, 1958, **100**, Sept. 21, 1295–1300). Some problems in sheet bend forming and the process of bending are discussed. (60 refs.).

Cold Drawing of Seamless Steel Tubes. A. Malegue. (*Technique Moderne*, 1958, June, 265–269). The author reviews the operations and installations involved in the cold drawing of seamless steel tubes. Dimensional specifications are discussed. Cold drawn steel tubes are stated to be suitable for carrying liquids at elevated temperatures and pressures.—R. P.

Position and Development of the Technique of Cold Extrusion of Steel. H.-D. Feldmann. (*V.D.I.Z.*, 1958, **100**, Sept. 21, 1300–1303). Advances in cold extrusion technique since the war, and the possibilities and limitations of the process are discussed.

ROLLING-MILL PRACTICE

On the Relation between the Groove Profile and the Distribution of Fibrous Flow in the Transverse Section of Hard Steel Bars, and Some Defects Appearing on the Surface. W. Ota. (*Nippon Kinzoku*, 1956, **20**, June, 304–308). The distribution of fibrous flow in high-carbon Cr steel rolled to various profiles is examined, and the relationship of decarburized layers, wrinkles, and cracks to this distribution is investigated.—K. E. J.

Study of the Operation of Strip Mills at Ural Works. N. I. Gubashev. (*Metallurg*, 1957, (12), 33–34). The work and recommendations of an interworks study group consisting of sheet-mill operators and other suitable personnel from several Ural works are outlined. The group operated in October, 1956.

Transverse Gauge Variation in Strip and Sheet Rolling. K. Saxl. (*Proc. I.M.E.*, 1958, preprint, pp. 13). The case of the two-high mill is formulated and a method of estimating edge thinning is given. Conditions in four-high and other backed-up mills are examined and compression and elastic effects are considered. A method of cambering and one for compensating for secondary deflection are suggested.

Continuous Rolling of Stainless Steel. (*Sheet Met. Ind.*, 1958, **35**, Apr., 245–258). An illustrated description of the Shepcote Lane rolling mill installed in Sheffield.

Corrugated Steel Foil Promises Lighter, Stronger Aircraft. B. Mitchell. (*Iron Age*, 1958 **181**, Feb. 6, 102–104). The development of corrugated steel foil by the Ryan Aeronautical Co. is described. By using very thin sheets of high-strength stainless steel, such as 17–7PH alloy, with tiny corrugations, supersonic aircraft may be made 25% lighter, or without adding any weight, made to withstand aerodynamic heating to 750° F. The material has a yield strength of 200,000 p.s.i. at room temperature. The 3 sizes made have top gauge limits of 0·003, 0·006, 0·009 ins. Welded to thin skin, the corrugated material provides a very rigid surface covering for aircraft. Welding techniques have been developed.—D. L. C. P.

Stress Distribution in the Cold Rolling of Tubes. Yu. F. Shevakin. (*Stal'*, 1958, (3), 235–240). The axial stress in the cold rolling of tubes increases in proportion to the increase in pressure of the metal against the rolls. The coefficient of friction between the metal and the mandrel exerts a powerful influence on the distribution of stresses. By altering the coefficient of friction alone, it is possible to reduce the pressure by five-sevenths and the tensile strength of the tube at the moment of feeding by half to one-third.—R. S.

Investigation on Rolling Oils and Oil Emulsions in Cold Rolling. II. Rolling Trials with Commercial Rolling Oils under Conditions Adapted from Industrial Operation. W. Lueg and P. Funke jun. (*Stahl u. Eisen*, 1958, **78**, Mar. 20, 333–343; discussion, 355–357). The interpretation of the results of the tests, which are described in detail, is impaired by the fact that the composition of the commercially available oils and emulsions was not known. However, it is clear from the results that grease made from long-chain, saturated fatty acids in either form, i.e. undiluted or emulsified, show good lubrication properties and are clearly superior to oils or emulsions of the mineral-oil basis. The emulsifier should not react with calcium ions.

Studies of the Properties and Usability under Works Conditions of Modern Rolling Oil Emulsions. J. Billigmann and W. Fichtl. (*Stahl u. Eisen*, 1958, **78**, Mar. 20, 344–357). The trials, and emulsions used are described in detail. It was found that the lubrication effect of emulsions depends more on the nature and structure of the base materials than on the free-acid content. Natural greases based on long-chain, saturated fatty acids are the most suitable. Even high-pressure additives do not improve the lubrication effect of mineral-oil-base emulsions to such an extent that they become comparable with natural greases.—T. G.

Republic Keeps Pace With Increasing Requirements for Fusion Welded Line Pipe. W. S. Schaefer. (*Reg. Tech. Meet. A.I.S.I.*, 1957, 333–367). An account of the plant, with many illustrations.

Steels for Tube Mills Working above 600 C. J. Ivernel. (*Rev. Nickel*, 1957, **23**, July-Aug.-Sept., 61–71). The hot-working properties of various austenitic steels are discussed. Titanium-stabilized high-alloy steels are suitable for temperatures between 600° and 650° C and show resistance to intergranular corrosion. (12 references).—R. P.

Seamless Tube Making by the Calmes Process. A. Calmes and C. A. Roberts. (*Iron Steel Eng.*, 1958, **35**, Feb., 124–131). The mill takes ingots directly from the O.H. furnace and makes seamless tubes in one continuous process. The ingots are round corrugated types, top-poured, weighing up to 8000 lb. The main operations are ingot conditioning, ingot heating, press piercing, elongating, rotary forging (on a Pilger mill), reheating, sizing, polishing, finishing and testing. The press piercing, elongating and rotary forging operations, which are basic and are performed in one heating cycle, are described in detail.

J. and L. Uses Simplified Gauge Control. (*Steel*, 1958, April 7, 110–113). A description is given of the principles governing the design of a gauge control for a strip mill at Jones and Laughlin's Aliquippa Works.—A. G.

Reel and Coil Transport Installations in Steel Mills for Rod, Bar and Narrow Strip. A. Hinders. (*Draht, German ed.*, 1958, **9**, Jan., 1–8). Design and operation of reels of pouring and laying types are described, followed by a description of the layout and constructional details of coil transport installations of the overhead suspension and conveyer belt types. Included are nomograms for the calculation of the length to be travelled to achieve the required cooling.—J. C. W.

Methods of Lowering Costs of Rolled Products. P. P. Zuev. (*Metallurg*, 1956, (6), 28–30). As in the "Electrostal'" Works the costs of metal represents 95% of the total production costs of the rolled products, saving of metal used per ton of rolled products is particularly important. The importance of carrying out metal balances for all stages of manufacture is stressed as such balances may point out where excessive losses are taking place.—V. G.

The Evershed Width Gauge. (*Brit. Steel.*, **24**, Mar., 88–89). The method of operation of the Evershed Width Gauge is described. It is a servo-driven optical arrangement for monitoring deviations in the width of hot strip in a continuous mill. The system relies on the natural infra-red radiation from the strip, and is sufficiently sensitive to respond to material that has cooled to a very dull red. Two 'followers' on a gantry over the roller-table are set to the nominal width of the strip, and photocells focused on the edge of the strip measure the radiation received; as other cells compensate for the temperature of the strip the position of the edges can be located. The accuracy of the width gauge is $+\frac{1}{16}$ in.

Strip Mill Control: Nucleonic Thickness Gauge Automatically Governs Screw-down. (*Iron Steel*, 1958, **31**, Jan., 8–10).

Non-Contact Automatic Gauge Control: First Installation in a Strip Mill. (*Brit. Steelmaker*, 1958, **24**, Jan., 18–21). The new Baldwin nucleonic thickness gauge, which is a non-contact, measuring and automatic gauge control device, is installed on a Robertson mill at the works of D. F. Taylor & Co. Ltd. Details are given of the principle and operation of the device.—G. F.

Mill Uses Fireproof Hydraulic Fluid. (*Steel*, 1958, **142**, Feb. 3, 117–120). The introduction of a water-in-oil emulsion as the hydraulic fluid for use in a rolling mill is described. The fire hazard has been removed; with petroleum hydraulic oil a fire had been caused by a hot slab breaking the hydraulic lines.

Magnetic Separators: Application to Cold Rolling Mill Coolant Systems. A. L. Wilson jun. (*Iron Steel*, 1958, **31**, Feb., 71–72). Recently the successful cleaning of rolling mill lubricants has been achieved by the introduction of magnetic separators as the major cleaning device on the coolant systems. The installation of the separators is described, and their advantages and limitations are discussed.—G. F.

Time Studies in Rolling Mills. K. Lehmann. (*Stahl Eisen*, 1958, **78**, Apr. 17, 505–509). The Swedish Ericsson Centralograph and its application to rolling mills is described and discussed. The results and improvements obtained by the use of this instrument are analysed.—T. G.

The Rolling Deformation Zone in the Light of I. M. Pavlov's Theory. J. Bazan. (*Hutnik*, 1958, **25**, March, 100–105). Two extreme models of the deformation zone with and without a speed gradient across two rolled planes are analysed. Some experimental work confirming Pavlov's theory is described.

Nomograms for the Determination of the Roll Force Based on the Ekelund Equation. A. Mathea. (*Stahl Eisen*, 1958, **78**, Oct. 2, 1 383–1 389). The Ekelund equation for rolling force and deformation resistance is briefly discussed and certain simplifications are introduced in order to facilitate the construction of nomograms. Two nomograms are presented and their use is explained. In case of difficulties in the rolling operations the nomograms can even provide the reasons for them.—T. G.

The Effect of Pressure Exerted by Rolls on the Quality of Flat Blooms. W. Leskiewicz. (*Hutnik*, 1957, **24**, Sept., 349–355). [In Polish]. The author describes experimental details of the taking of samples of metal from blooms rolled in three different numbers of stages (35, 23, and 19). Physical properties such as plastic limit, tensile strength, elongation, etc. were tabulated and are discussed for different samples.

Plastics as Bearing Materials in Rolling Mills. Scheel. (*Technik*, 1958, **13**, Feb., 108–110). Details of design and performance of plastic roll-neck bearings are quoted, including friction coefficients, mechanical and thermal properties.—J. G. W.

Bar and Rod Mill. (*Draht*, 1958, **9**, Mar., 81–83). The new continuous mill at the Klöckner-Hüttenwerk Haspe A.G., Germany is described and illustrated. The mill, built by Schloemann AG., and commissioned in 1956, is laid out for two-strand rolling of bar stock and four-strand rolling of wire rods in appr. 1000 lb-coils, finishing bars at about 900° C and 2400 ft/min, and rod at up to 6000 ft/min. The electric drive, by Brown-Boveri & Cie, is by rectifier-supplied and electronically controlled D.C. motors.—J. G. W.

New Production Method for Joists, Particularly of Light Section. H. Sedlaczek. (*Rev. Mét.*, 1958, **55**, Apr., 333–338). A new method is described of rolling joists of light section. This allows for the transverse cutting of the flanges in the original section and at the same time makes use of the Rendleman method which allows the rapid reduction in web thickness by means of a toothed roll.—B. G. B.

Sendzimir Planetary Rolling Mill. P. Blain. (*Centre Doc. Sidér.*, 1958, (4), 853–859). The principle of this type of mill is first described and then a description of the Sendzimir mill installed at SAFIM in Milan is given.—B. G. B.

The Use of Protective Atmospheres in Cold-Rolling Mills. W. Feige and P. Middelhaufe. (*Stahl Eisen*, 1958, **78**, Oct. 16, 1441–1448). In the process annealing of low-carbon steel strip the bright surface should be retained, but of high-carbon steel strip the composition, particularly the carbon content, should not be altered. The theory of the conditions of bright annealing including $CO/CO_2 : H_2/H_2O$ ratios, humidity and dew point, etc., is discussed. The production of protective atmospheres and their application including costs are described and the control of protective atmospheres and their instrumentation briefly dealt with.—T. G.

An Analysis of the World Trend Towards the Development of Seamed Tube Rolling Mills. W. Dobrucki. (*Hutnik*, 1958, **25**, Apr.-May, 156–164). Trends are reviewed on the basis of the foreign literature.—M. T.

Examination of Theories of Tube Reduction. N. Torma and R. Hantos. (*Koh. Lapok*, 1958, **13**, April, 191–195). The authors compare various theories of hot tube reduction with operation measurements. Wall-thickness results calculated from rolling rate, using Prof. Geleji's method, equal those obtained by practical measurements.—F. K.

Centralised Manufacture of Tools for Tube Rolling Mills. Yu. I. Nikolaevskii and M. Ya. Krichevskii. (*Stal'*, 1958, (7), 633–635).

Roller Guides for Hot Mills. Kalpers. (*Draht*, 1958, **9**, Mar., 83–84). Uses and designs of roller guides are described, with reference to Swedish practice.—J. G. W.

A Computer for the Automatic Control of the Shearing of Rolled Stock. V. L. Epshtein. (*Stal'*, 1958, (7), 622–628).

Automatic Loop Drives in a Continuous Hot Rolling Mill. R. Hagel and J. Jonca. (*Hutnik*, 1957, **24**, Dec., 488–494). [In Polish]. Automatic loop drives in a continuous hot rolling mill equalise changes of electrical, mechanical and technological parameters during the process of rolling. The design and method of calculation of the loop drive, also the adjustment of the size of the loop are described. At a medium speed of rolling (about 5 m/sec) it is possible to regulate the number of revolutions by changing the voltage supply to the motor with the aid of additional generators. At higher rolling speeds, adequately rapid regulation is obtained by individually supplying the dividing motors from rectifiers.

The Measurement of Strip Tension in the Rolling Process by a Direct Method. J. Golek. (*Hutnik*, 1958, **25**, Jan.-Feb., 34–39). [In Polish]. Methods of direct measurement of tension in cold rolled strips are described. Single and three-roll trains are described and the experimental results obtained are discussed.

Trends in Automation Applied in Iron and Steel Works. H. Vogl. (*Stahl Eisen*, 1958, **78**, July 24, 1033–1038). A number of possible applications of automatic operations in a rolling mill are discussed.—T. G.

Automation in Iron and Steel Works. H. Cordes. (*Stahl Eisen*, 1958, **78**, July 24, 1071–1073). A number of control elements for operation of rolling mills and their mode of operation are discussed on the basis of published information.—T. G.

Automation of Reversible Mills. C. Roger. (*Centre Doc. Sidér. Circ.*, 1958, (4), 861–869). A review is given of the present state of automation as applied to reversible mills. American installations at Homestead, Geneva Steel, Granite Steel Co., Inland Steel Co., Allegheny Ludlum, and Aliquippa are discussed.—B. G. B.

The Control of Thickness on a Cold-Rolling Single-Stand Mill. B. Fazan. (*Rev. Gen. Méc.*, 1958, **42**, June, 302–305). A largely graphical treatment of the problem is given.

'Betatest' Instrument for Non-contact Thickness Measurement. H. Harder. (*Draht*, 1958, **9**, Mar., 91–94). Following an exposition of the principles of measurement, discussion of the choice of source, response, sensitivity, and errors of beta-ray thickness measurements, particulars of the 'Betatest' equipment are stated.—J. G. W.

Formation of Internal Cracking in Blooms and Ingots During the Rolling Process. J. Gorecki. (*Hutnik*, 1957, **24**, June, 228–234) [In Polish]. Formation of internal cracks and their causes are discussed. The effect of the initial height (h.) and change of height (Δh) of ingots and the diameter of the rolls (Der) are analysed. In order to prevent internal cracking it is recommended: (1) To use large rolls in the first stages; (2) To use small and well heated ingots.

The Influence of Steelworks Process on the Fracture of Steel Ingots During Rolling. T. Mazanek and J. Koza. (*Hutnik*, 1957, **24**, June, 218–221). [In Polish]. The production of steel for one year from one of the steelworks is analysed. Different factors influencing the number of fractures of ingots were investigated and the following conclusions derived: (1) The least number of fractures occurred when the ratio Mn/S was at least 6.5; (2) The content of Si ought to be maintained at its lowest limit; (3) To prevent rapid cooling, large ingots are recommended; (4) To prevent fractures of steel ingots of high S content, high temperatures should be maintained in rolling.

MACHINERY AND SERVICES FOR IRON AND STEEL PLANT

Supply and Control Cables for Steelworks. J. H. Braddy. (*Brit. Steel.*, 1958, **24**, Sept., 298–301). Planning, installation, and testing are described.

Water Economy in Iron and Steel Works. F. Wesemann. (*Jernkont. Ann.*, 1958, **142**, (6), 271–288). [In German]. A detailed survey of the subject, dealing with open and closed water supply systems, water purification, and economic considerations. (15 refs.).

WELDING AND FLAME CUTTING

Deep-Penetration Welding with Shielded Electrodes. Results of Tests Carried out at the Institute of Welding.—IV. Results (Part 2): Influence of Electrical Characteristics on the Extent and Regularity of Penetration. Studies Regarding the Soundness and Mechanical Characteristics of Joints. A. Gaubert. (*Soud. Techn. Connexes*, 1958, **12**, July/Aug., 249–262). The author reports on studies regarding the relative variation of penetration in relation to electrical variables and their effect on joint soundness. The latter also depends on welding speed, length of arc, and water content of the shield. The mechanical characteristics of the joints are discussed. The given data can serve as a guide for choosing optimum power supply and welding procedure.—R. F.

A Change in the Method of Air Blasting Skelp in the Furnace Welding of Tubes. T. I. Romershtein. (*Metallurg*, 1958, (3), 31–32). Defects in the present methods of compressed air blasting the edges of skelp are eliminated by top blowing instead of lateral blowing.

Fundamental Resistance Welding Investigations. First Interim Report. D. K. Roberts, J. E. Roberts and A. A. Wells. (*Brit. Weld. J.*, 1958, **5**, March, 117–126). Temperature cycles during spot welding were examined theoretically and experimentally. Rates of heating and cooling have been calculated with the assistance of a non-dimensional variable. A method is described of placing and recording from thermocouples close to spot welds.

Investigations into the Electro-Slag Process. R. Müller. (*Schweissen Schneiden*, 1958, **5**, Sept., 359–367). Investigations into the electroslag welding process carried out in Western Germany are described. Tests in the normalized state on the difficultly-weldable St 50 gave a weld quality comparable with that of the base metal. 3-Wire welding equipment showing some improvements on the Soviet equipment was then constructed, and early tests were free from macro defects.

Spot Welding of Rail Steel. D. Canonico and H. Schwartzbart. (*Weld. J.*, 1958, **37**, May, 484–488). The results of a survey of companies that are successfully spot welding re-rolled rail steel are presented as four case histories.

Seam Welding Galvanised Steel. W. J. Allen and M. L. Begeman. (*Weld. J.*, 1958, **37**, Apr., 138s–143s). The changes in welding variables necessary to produce acceptable seam welds with zinc-coated steel sheets were determined. Interrupted welding currents having long 'off' times were undesirable, but continuous currents gave good nugget penetration over a wide current range. Higher currents and higher electrode forces were necessary to obtain the same nugget penetration as with uncoated sheets. Welds of satisfactory penetration retained little zinc coating in the weld area but still had considerable corrosion resistance.—B. C. W.

Tungsten-Arc Welding of 0·002 in. and 0·005 in. Stainless Steel and Titanium. J. C. Collins and S. P. Jenkins. (*Weld. J.*, 1958, **37**, Apr., 342–347). The development of a technique for butt welding very thin sheets of stainless steel is described together with the results of mechanical tests on the welds. The arc was initiated by using argon but the actual weld was made with helium as a gas shield. Although the sheets were clamped and moved under a fixed welding head the process could not be considered automatic as the quality of the final weld depended on the judgment of the operator.—B. C. W.

Recommended Practices for Radiographic Inspection of Fusion-Welded Joints for Steel Plates up to 2 in. Thick. (*Soud. Techn. Connexes*, 1958, **12**, 291–294). This paper summarizes general recommendations for X-ray

and gamma-ray examination of butt welds in mild or low-alloy steels. Protection of operators and identification of radiographs are discussed, also films, screens, viewing, and the use of image quality indicators.—R. P.

Effects of Steel-Making Practice on Submerged-Arc Weld Porosity. J. T. Lapsley jun. (*Weld. J.*, 1958, **37**, Apr., 169s–178s). The effects of steelmaking practice and processing variables on the susceptibility of 10 heats of nominally similar low-carbon steel to weld porosity in submerged arc welds were studied. Significant variation in weld porosity sensitivity was found among the steels but the severity was less than that caused by inferior weld preparation. Susceptibility to weld porosity appeared independent of deoxidation practice and was not attributed to differences in O, C, S, Mn, Al, Si, and P contents. The greatest differential sensitivity within individual heats was associated with sheet position, internal sheet material welds being less susceptible than those from as-rolled sheet edges. Causes for the variations in susceptibility to weld porosity were not isolated or determined.—B. C. W.

A Study of Factors Affecting the Strength and Ductility of Weld Metal. C. M. Wayman and R. D. Stout. (*Weld. J.*, 1958, **37**, May, 193s–200s). The results are presented of an investigation into the factors responsible for the high yield strength/tensile strength ratio and the reduced ductility of weld metal in unalloyed carbon steel. Two welding processes, submerged-arc and inert-gas shielded metal arc, were used and the factors studied included preheat, travel speed, current, number of passes, heat treatment, restraint during welding and prestrain of weld metal at elevated temperatures. The main conclusions were (*a*) that variations in current, voltage, and travel speed can be considered as changes in energy input, (*b*) heat treatment of weld metal to give cooling rates and grain size comparable to those obtained in welds did not result in a high yield stress and yield ratio but the ultimate stress was similar to that in weld metal, (*c*) weld metal deposited without restraint in a copper plate did not show a high yield stress and yield ratio, (*d*) normalized weld metal prestrained at elevated temperatures showed a yield point return, a high yield stress, and a high yield ratio, and (*e*) the unusually high yield stress and yield ratio in weld metal are believed to be a result of plastic strain occurring during cooling. (65 references).—B. C. W.

Dynamic Measurement of Stress Associated With Weld Cracking. S. S. White, W. G. Moffatt, and C. M. Adams jun. (*Weld. J.*, 1958, **37**, Apr., 185s–192s). A method is described for measuring the transient stresses during and after welding. The specimen was a slotted plate and interpretation of the strain gauge readings depended on the application of the theory of beams on elastic foundations. Neither the method of measurement nor the analysis was sensitive to plastic deformation in the immediate region of the weld. For Mn–Mo armour plate the maximum transverse distributed load which preceded cracking appeared to be less dependent on welding conditions than on filler composition. With low carbon filler metal cracking was accompanied by more plastic deformation and a greater time delay than with high carbon filler metal.

A Quantitative Evaluation of Residual-Stress Relief in Pipe Weldments. J. E. Cook and R. B. McCauley. (*Weld. J.*, 1958, **37**, Apr., 179s–184s). The distribution and relief of residual stresses in butt welds in 4 in. diameter, 0·337 in. thick pipe was studied, using an X-ray diffraction method without part sectioning to determine the residual stresses, and induction heating to relieve them. The effects of temperature, soaking time, and rate of heating on stress relief were examined.

Effect of Time on the Hydrogen Content and Mechanical Properties in Arc Welds With Shielded Electrodes. W. Hummitzsch. (*Soud. Techn. Connexes*, 1958, **12**, July/Aug., 269–276). Test bars and specimens for the determination of the H_2 content were taken from 4 h to 5100 h after welding, the weld deposits having been effected with various acid, basic, and rutile electrodes. Results showed that the H_2 content in the weld metal decreases with time until a minimum value is reached. The effect on mechanical properties is variable.

Some Factors Which Play a Part in the Adhesion of Materials. C. Jouwersma. (*Metalen*, 1958, **13**, Aug. 30, 284–289). Theoretical considerations of the magnitude of intermolecular forces indicate values for the strength of an adhesive bond which greatly exceed those found experimentally; the causes for this are discussed in relation to the influence of internal and external stresses and other factors.

New Experiences and Knowledge Gained by Flame Cutting with the Oxygen Powder Lance. H. G. Kluge. (*Schweissen Schneiden*, 1958, **5**, Sept., 368–373). A description of investigations into the use of the oxygen powder lance for flame cutting (of reinforced concrete), with economic considerations and a comparison with other methods.

MACHINING AND MACHINABILITY

Machining Performance of a Home-made Ceramic Tool and Its Wear Process. H. Takeyama and T. Murai. (*J. Mech. Lab.*, 1958, **12**, July, 118–124). Comparison with carbide tools was made in the machining of Mechanite cast iron and an alloy steel. A cylindrical insert tool gave good performance on the former but more work is required to obtain tools suitable for alloy steel.

Machinability Study of a Ceramic Tool. I. Ultra High Speed Lathe for Machinability Studies on Ceramic Tools. H. Mii, K. Yamada, N. Nakayama, E. Ota, H. Kajiwara, and S. Sakai. (*Rep. Gov. Ind. Res. Inst.*, 1958, **7**, Sept., 638–642). [In Japanese]. The lathe is driven by a 7·5 h.p. a.c. motor; at the max. speed of 10 000 r.p.m. a 100-mm dia. work piece moves nearly 3000 m/min. At 8000 rev/min the no-load temp. rise of the bearings was below 20° C; the amplitude of vibration of the spindle cover was 3–4μ and that of the bed 3μ. Tests with ceramic tools showed the suitability of the lathe.—K. E. J.

Hard Metal Versus High Speed Steel. J. Videm. (*Jernindustri*, 1958, **39**, May, 91–97, 110–116). A comparison of the properties and application of hard metals and high speed steel for tool manufacture, in relation to the Norwegian machine tool industry.

Choice of (Cutting) Edge Material for Chip-Cutting Machining. H. Strom. (*Jernindustri*, 1958, **39**, June, 129–141). This section deals with the theoretical principles of chip cutting, classification of materials and types of machine tools.

Data on the Milling of Alloyed and Unalloyed Constructional Steels with Hard Metal. Part I. H. Opitz, K. H. Frohlich, and H. Siebel. (*Forsch. Wirts. Nordrhein-Westfalen*, 1956, No. 207, pp. 38). Tests on C35 carbon steel are described. **Part II.** H. Opitz, H. Siebel, and R. Fleck. (1957, No. 413, pp. 44). CK60 and 16-Mn-Cr-5 steels are examined.

Machining Ultra-High-Tensile Steels. H. J. Pearson. (*Aircraft Prod.*, 1958, **20**, Feb., 75–83). Turning, face milling, slot-milling and end-milling, and end cutting tests are tabulated and discussed.

Ultrasonic Mechanical Machining. (IV). G. Nishimura and S. Shimakawa. (*Tokyo Univ. J. Fac. Eng.*, 1958, **25**, Mar., 213–235). Experiments on glass are described.

Ultrasonic Electro-Spark Machining. II. C and R Effects. G. Nishimura, K. Yanagishima, and T. Shima. (*Tokyo Univ., J. Fac. Eng.*, 1958, **25**, Mar., 237–242). C is capacity and R is resistance and the electrical parameters and their influence on efficiency are evaluated. **III. Ultrasonic Electro-Spark Machining with Low-Frequency Vibration in the Work-Piece.** G. Nishimura and S. Shimakawa. (243–246). An oscillation of 0·1 mm at 100 c.p.s. was used for machining high-speed steel with a brass tool working at 20μ amplitude and 28 kc/sec. **IV. Theory of Ultrasonic Electro-Spark Machining with Low Frequency Vibration of the Work-Piece.** (247–251). **V. Dimensional Effect and Deep Hole Machining.** G. Nishimura, K. Yanagishima, and T. Shima. (253–259).

CLEANING AND PICKLING

Ultrasonic Cleaning. I. G. Nishimura and S. Shimakawa. (*Tokyo Univ. J. Fac. Eng.*, 1958, **25**, Mar., 261–266). **II.** (267–274). The effects of various factors, including solvent, on cleaning efficiency are evaluated. Xylene was the best solvent tried.

Chemical Polishing. L. F. Spencer. (*Met. Fin.*, 1958, March, 52–56). In non-electrolyte dipping, the basic processes are cleaning and immersion in a hot solution appropriate to the alloy treated. The theory is outlined and suitable solutions for copper and copper base alloys are listed.—A. G.

Rapid Descaling of Ferrous Metals: The Use of Activating Agents. L. Mauri Font. (*Acero Energ.*, 1958, **15**, July-Aug., 48–50). [In Spanish]. The removal of oxide coatings in pickling baths is discussed. The action of wetting agents, the method of adding them, the addition of inhibitors, and a phosphoric acid pickling bath are also described.—P. S.

Acid Pickling of Iron and Steel. A. G. Gardner. (*Met. Fin. J.*, 1955, **1**, Mar., 117–122). A general review of equipment, acid concentrations, restrainers, and other topics is given.

PROTECTIVE COATINGS

Corrosion-Protection of Iron and Steel. S. Rajagopalan. (*Iron Steel Rev.*, 1958, **1**, Feb., 59–61). Various methods of producing protective coatings on iron and steel are summarized.—B. C. W.

Finishing Vauxhall Motor Cars. (*Prod. Fin.*, 1958, **11**, May, 44–81). An illustrated account of the automatic plating department, with effluent disposal, and of the paint finishing plant is given.

A Simple Non-Destructive Thickness Gauge for Electrodeposits. A. R. Heath. (*Met. Fin. J.*, 1955, **1**, Apr., 145–150). A thermo-electric device is described and its development and testing set out.

Pollution by Metallurgical Trade Wastes. E. W. Mulcahy. (*Met. Fin. J.*, 1955, **1**, July, 289–297, 300). A review of the objectives of treatment and of treatment methods and installations as well as preventive and recovery methods inside the factory is given.

Recent Developments in Chromium Plating. H. Silman. (*Met. Fin. J.*, 1955, **1**, Jan., 11–14). A review of various bath compositions and methods such as barrel and tampon plating is given. (17 refs.).

On the Effect of Substances Containing Bivalent Sulphur on Nickel Plating. A. V. Pamfilov and R. M. Morgart. (*Ukrain. Khim. Zhur.*, 1957, **23**, (5), 684–688). Substances containing sulphide-S produce a bright deposit in electrolytic Ni plating. The mechanism of the reactions taking place is discussed.

Electrodeposition of Nickel and Cobalt Alloyed with Phosphorus. M. Lorant. (*Met. Fin. J.*, 1955, **1**, Mar., 130–131). A review of the N.B.S. process.

Progress in Galvanizing. (*Usine Nouv.*, 1958, Sept. (Edn. Meusuelle), 37, 39). A new Sendzimir galvanizing line set up at Montataire in 1957 with a capacity of 10 t/h and 6000 t/month and 260 m long is described.

Dry Galvanizing. H. Bablik and F. Gotzl. (*Met. Fin. J.*, 1956, **2**, Oct., 365–367). A discussion of the process in comparison with the wet method. As here described it has few advantages.

The Influence of Surface Condition on the Galvanizing Properties of Steel Sheets. H. Bablik. (*Met. Fin. J.*, 1955, **1**, Jan., 5–10). The "dry process" using Al-containing baths was examined and metallographic and spectrographic findings are reported. Various defects are illustrated and discussed.

An Experiment on the Effect of Type of Steel and Aluminium Content of the Bath on the Weight of Galvanized Coatings. N. B. Rutherford. (*Met. Fin. J.*, 1955, **1**, Feb., 71–75). The effects of rise of Al content and of immersion time on sheets and sections of steel were examined.

The Effect of Aluminium Additions to an Experimental Hot-Dip Galvanizing Bath on the Rate of Attack on Steel. N. B. Rutherford.

(*Met. Fin. J.*, 1955, **1**, June, 276–277). The effect of 0·1% Al was to increase the rate of attack by ~ 13·5%.

Study of Structure and Phase Composition of Coatings in the Hot Tinplating of Sheet Iron. A. I. Vitkin, T. P. Plotnikova, and G. A. Kokorin. (*Doklady A.N.*, 1958, **119**, (2), 268–270). The underlayer of the tinplate coating, studied with the help of tracer tin isotopes and by electronographic methods, is mainly composed of tetragonal crystals of $FeSn_2$. The underlayer is made of light and dark patches which differ only in their compactness and in the development of crystals of SnO_2. Lattice parameters of the various layers of the coating are given.—S. I. T.

The Use of Radioactive Isotopes in Studying the Mechanism of the Basic Processes in Hot Tinplating. A. I. Vitkin. (*Doklady A.N.*, 1957, **115**, (4), 710–713). To determine the mechanism of hot tinplating tracer isotopes of tin (^{123}Sn) and iron (^{59}Fe) were introduced in turn into the melt and into the flux ($ZnCl_2$). This allowed the construction of schemes shown, the migration and combination of tin, iron, and chloride in the flux and in the tin melt, and their action on the steel plate. Two diagrams illustrate these processes.—S. I. T.

Attempts to Improve Titanium Coatings on Iron, Deposited Non-Electrically. M. E. Straumanis and Y. P. Huang. (*Metall*, 1958, **12**, June, 501–503). Titanium coatings on iron are highly corrosion resistant: the iron does, however, suffer attack through the few pores present in the coating. NaCl solution provides a convenient qualitative test medium: corrosion being marked by yellow discoloration or stains on the surface of the object tested. The weight of the titanium coating can be increased by using a copper or silver base. Any remaining pores are closed by slight scraping, treatment with $AgNO_3$ solution, and renewed application of titanium.—L. J. L.

Electric Furnaces for Vitreous Enamelling. K. Roney. (*Met. Fin. J.*, 1955, **1**, Feb., 62–63, 76). The installation of Thomas De La Rue Co. Ltd. is described with details of performance.

New Silicate Protective Layers on Metal Surfaces. O. Loebich. (*Werkstoffe Korrosion*, 1958, **9**, July, 423–424). The Inverron layer, a new silica protective coating for metals, is produced by flocculating a SiO_2 gel under special and standardized conditions, followed by an ageing treatment. The film of oxide adsorbed on the metal surface reacts with the SiO_2 film to form a thin silicate bonding film. The SiO_2 film is resistant to temperatures up to 400° C, and does not impair the polish of the metal surface.—L. D. B.

Mechanization in Enamelling: A Symposium. Pickling and Pretreatment. J. Stack. (*Met. Fin. J.*, 1956, **2**, Oct., 373–375, 379). A review of proceedings at the Annual Conference of the Inst. of Vitreous Enamellers, Brighton, 1956. **Enamel Application.** W. B. Noon. (376–379). A further review.

Direct Application of Finish-Coat Vitreous Enamels to Sheet Steel. (*Met. Fin. J.*, 1955, **1**, Jan., 29–42). A report of a symposium. **General Considerations.** A. W. Murdoch. (29–33). **Shop Practice.** B. Zick. (33–36). **Discussion.** (36–42).

Solubility of Iron Oxides in Silicate Melts with or without Boron. K. P. Azarov and V. V. Balandina. (*Doklady A.N.*, 1957, **115**, (6), 1146–1147). Oxides of iron were added to silicate enamels and melted at 850° C for 10 h and at 950° C for 4 h and then quenched in water. The solubility of iron oxides in enamels was determined by the method of Andrews and Swift, which is based on a linear function of refractive index against the percentage of iron oxides dissolved. A series of curves showed that the solubility of iron oxides in boron-containing enamels was higher than in those free from boron.—S. I. T.

Enamel Adhesion and Chemical Constitution of Cast Iron. A. Hauttmann. (*Giesserei*, 1958, **45**, May, 301–304). A description is given of the statistically determined correlation between enamel adhesion and degree of saturation, Si, P, Mn, S, and C.—L. J. L.

The Use of Radioactive Isotope Tracer Technique in a Study of the Adhesion of Enamel Coatings. M. Lorant. (*Met. Fin. J.*, 1955, **1**, May, 196–198). Radio-cobalt was used as tracer and various mechanical and chemical processes were followed and interpreted.

Improved Coatings for the Protection of Water-sealed Gas Holders. (*Corros. Prev.*, 1958, **5**, Feb., 44–46). A brief description is given of the experience that led to the improved protection obtained since 1955 in Birmingham on one of the Windsor Street gas holders. Two rings of each of the two lower lifts were given two coats of Anotect Metallic Primer and one coat of Brymod C.B. Enamel. This system provided a primer based on zinc and "Epikote" resin to give solvent resistance and anti-corrosive properties with the top coat of "Epikote" resin-based enamel to consolidate the solvent and chemical resistance. Other lower lifts have been similarly satisfactorily treated.—L. E. W.

Surface Protection by Whirl Sintering and Flame Spraying. E. Gemmer. (*Werkstoffe Korrosion*, 1958, **9**, July, 421–423). Problems associated with the application of thin coatings of high polymer plastics to metal surfaces are discussed. A brief outline of the whirl sintering and flame spraying processes is given, and the two techniques are compared.—L. D. B.

A Fight to the Finish. A Review of the Anti-Corrosion Battle Waged by the Paint Industry. G. H. Gates-Reed. (*Iron Steel Rev.*, 1958, **1**, Feb., 81–82). The high cost of corrosion is stressed and the importance of applying protective paints to steel correctly is emphasized.

CLAD SHEET AND HARD-FACING

Plate Coated With Stainless Steel. (*Acciaio Inossid.*, 1958, **25**, May-June, 77–80). [In Italian]. The article describes a method of coating steel plate with a thin layer of stainless steel sheet. The process consists in sandwiching the carbon steel between two layers of stainless sheet and rolling the whole together.

Aluminizing of Iron with Aluminium Monochloride Vapour. S. A. Semenkovich and A. M. Smirnov. (*Metalloc. Obrabotka Met.*, 1958, (5), 48–51). The interaction at 950–1000° C produces a heat-resisting coating, the hardness of which appears to be due to Al_3Fe_2. At higher temperatures the coating is softer and is formed of the $FeAl_3$–Fe_2Al_5 eutectic.

Production of Copper-Clad Steel Tubes. F. Storek and J. Prošek. (*Vyzkumne Prace z Oboru Železa a Oceli*, 1958, 149–155).

Experimental Production of PN Material. (Strip Steel Clad with Ni and Al). M. Žudek. (*Vyzkumne Prace z Oboru Železa a Oceli*, 1958, 27–45). Fabrication by rolling to a final thickness of 0·006 in. of which 10% is Ni and 10% Al was carried out. The Czech steels giving the best results are named, recrystallizing perfectly at 535 ± 5° C after 90% reduction and 10 h annealing. Steel clad with Ni on one side was hot-rolled to 10 mm and cold rolled after conditioning to 2·2 mm. It was then clad with Al. Finished strip was annealed 15–20 h at 335° C.

Hard Surfacing Eliminates Unnecessary Replacement Costs. (*Weld. J.*, 1958, **37**, Apr., 362). The oxy-acetylene hard-surfacing of pipe-line discs and seat rings is briefly described.—B. C. W.

POWDER METALLURGY

Sintered Mechanical Parts. R. Hauser. (*Technique Moderne*, 1958, June, 297–306). The author reviews sintered plain and alloy iron and steels, with special reference to their properties for mechanical parts. Sintered material is classified according to porosity. The principles of sintering are discussed briefly and the pressing and sintering plant is described. Advantages and limitations to the use of sintered mechanical parts are pointed out. Various methods of corrosion protection are compared.—R. F.

Low-Temperature Moulding: Development of a Steel-Powder and Resin Material Having Stable Characteristics for General Tooling Applications. (*Aircraft Prod.*, 1958, **20**, Feb., 84–86). A material known as Rezalloy is described with notes on its uses.

Sliding and Frictional Materials Manufactured by Powder Metallurgy. F. Eisenkolb. (*Abhandlungen der Deutschen Akademie der Wissenschaften zu Berlin, Mitteilungen der Sektion für Maschinenbau, Akademie Verlag*, 1958). After a general description of the process of manufacture of sintered iron, steel, and bronze, as used for bearing and friction materials, plain porous bearings are dealt with and the main improvements achieved in recent years discussed, with particular reference to lead-bronze. Sintered piston rings are in full scale production in Czechoslovakia, although not yet in Germany. The use of iron with graphite and/or P additions is discussed, with examples from the textile industry and other applications. The effect of varying the composition of sintered compounds with an iron–graphite basis is discussed.

FERRITES, CERMETS, AND CARBIDES

On the Constitution of Copper Ferrite. I. Kushima and T. Amanuma. (*Nippon Kinzoku*, 1956, **20**, Aug., 473–476). Copper ferrite can dissolve Fe_2O_3 at high temp.; this is brought out of solution by annealing above 550° C. One kind of ferrite has a spinel structure (CuO, Fe_2O_3), and the other a rhombohedral structure (Cu_2O, Fe_2O_3). The latter is formed above 1 100° C. (17 references).—K. E. J.

A Note on the Preparation of Manganese (II) Ferrites. A. Bergstein, M. Rozsival, and M. Mikulaš. (*Chem. Listy*, 1958, **52**, (10), 1856–1865).

An Improved X-Ray Method for Determining Cation Distribution in Ferrites. L. P. Skolnick, S. Kondo, and L. R. Lavine. (*J. Appl. Phys.*, 1958, **29**, Feb., 198–203).

Influence of Copper and Vanadium on the Sintering of Magnesium-Type Ferrites. L. C. F. Blackman. (*J. Appl. Phys.*, 1957, **28**, Dec., 1511–1512).

PROPERTIES AND TESTS

Erratum

Vol. 191, Jan. 1959, p. 98, col. 1.
Line 5 from bottom.
For "54–65" read "44–55."

Proposed Recommendations Affecting Standards on Steel. (*Proc. A.S.T.M.*, 1957, **57**, 85–92). Additions and corrections to numerous tentative specifications are given.

Internal Friction Measurements on Pure α-Iron and Technical Steel. H. J. Seemann and H. Finkler. (*Annales Universitatis Saraviensis*, 1956, (5), reprint 87–105). An account of Snoek-damping as a method of determining N and C in α-iron. Other alloying elements have effects in steel, and results on the effects of P in particular are presented.

Study on Spring Materials. VII. H. Hotta. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 38–42). [*In Japanese*]. Data are given for max. hardness, Izod values, fatigue strength and torsional stress values of Si–Mn steel and No. 5 die steel (analyses given), and the appropriate heat treatments.—K. E. J.

Peak of Internal Friction Connected With Diffusion of the Hydrogen Molecule, Caused by Stresses in High-alloy Chromium Nickel Steels. Kun Chin-sin and Ke Tin-sui. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 82–90). (Translation from English; original appeared in *Acta Physica Sinica*, 1957, **13**, No. 2). No peak of internal friction ascribable to viscous slipping along grain boundaries of steels with 25% Cr and 21% Ni, or other high-alloy steels was observed. This is in contradiction to the works of Rozin and Finkelshtein published in 1953. To confirm this observation, measurement of internal friction were carried out on coarse-grained specimens with a grain size of ~ 250μ which was twice the size of the grains with which Rozin and Finkelshtein worked. Results of these tests confirm that the peaks cannot be attributed to viscous slipping along grain boundaries.—L. H.

Investigation by Internal Friction of the Tempering of Hardened Steels. I. N. Cherni-

kova. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 102–105). The relation between internal friction in carbon steels and their thermal treatment, for various concentrations of carbon, was investigated by the method of torsional oscillations of small amplitude. The carbon contents of the steels investigated were: 0·015, 0·28, 0·35, 0·45 and 0·58% over the range from room temperature to 600° C. The results are presented graphically, together with a full discussion regarding their interpretation.—L. B.

The Plastic Flow and Fracture of a 'Brittle' Material (Grey Cast Iron) with Particular Reference to the Effect of Fluid Pressure. B. Crossland and W. H. Dearden. (*Trans. I.M.E.*, 1958, *preprint*, pp. 12). Torsion tests were carried out with superimposed fluid pressures up to 35 t/in². Mode of failure appears to depend upon the volumetric stress acting. Shear stress-strain curves are obtained and discussed and are also apparently related to volumetric stress. In torsion, strain to failure is raised by pressure and rate of change of strain is increased when fluid pressure suppresses any tensile component.

Analysis of Elasto-Plastic Behaviour of Metals by Means of a Photoelastic Coating Method. K. Kawata. (*J. Sci. Res. Inst.*, 1958, **52**, Mar., 17–40). Epoxy–polysulphide copolymer is used as a photoelastic material and practical examples of its use for solving stress concentration problems are given.

Three-Centre Integrals in Iron. M. Suffczynski. (*Bull. Acad. Polonaise Sci.*, 1958, **6**, (3) 195–198). A mathematical treatment of the constants in the matrix components of energy is given.

The Texture and Mechanical Properties of Iron. C. J. Ball. (*JISI*, 1959, **191**, Mar., 232–236). [This issue].

Some Aspects of Preyield Phenomena in Mild Steel at Low Temperatures. W. S. Owen, M. Cohen and B. L. Averbach. (*Trans. A. S. M.*, 1957, **50**, Preprint 9, pp. 37). The sequence of events leading to gross yielding at − 196° C has been explored by metallographic techniques, by the observation of strain patterns on long thin prepolished specimens and by precise strain measurements as a function of stress and time. The implications of the data are briefly discussed in qualitative terms by reference to the Clark-Wood dislocation model.—E. E. W.

Effect of Micro-structure and Heat-Treatment on the Mechanical Properties of A.I.S.I. 431 Stainless Steel. G. E. Dieter. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 18, pp. 26). Transverse tensile tests on commercial forgings show that the transverse ductility is considerably improved if no delta-ferrite stringers are present. The transverse ductility is sensitive to quenching temperature, and retained austenite reduces the yield strength. The latter effect may be minimized by refrigeration.—E. E. W.

The Effect of Rate of Stress Application and Temperature on the Upper Yield Stress of Annealed Mild Steel. J. A. Hendrickson and D. S. Wood. (*Trans. A. S. M.*, 1957, **50**, *Reprint* 27, pp. 13). Two theoretical predictions are presented, both based on basic concepts of dislocation theory, but differing in various assumptions and approximations. Experimental measurements have given results in good agreement with both forms of theory.—E. E. W.

Brittle Fracture of Mild Steel in Tension at − 196° C. W. S. Owen, B. L. Averbach and M. Cohen. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 41, pp. 22). Strain pattern and microscopical changes preceding fracture were observed and the local strain situation was measured on long-strip mild steel specimens at testing speeds of between $8{\cdot}9 \times 10^{-4}$ and $1{\cdot}6 \times 10^{-1}$ in./min. The observations were compatible with Low's application of the Griffith-Orowan concepts rather than with the dislocation pile-up theory.—E. E. W.

Measuring Local Strain under Static Load. Rapid Replica Technique (*Engineering*, 1958, **185**, June 6, 726–727). A method developed at the Royal Aircraft Establishment is described in which a scratch pattern is lightly inscribed on a specimen and replicas taken before and after straining are compared.

Volume Deformation in Bending. Yu. E. Bondarev. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 106–109). Uniform elongation of a metal under stress is a characteristic of its strength and determines under constant conditions the magnitude of its volume deformation in unnotched specimens: also the spreading of deformation. Metals with large uniform elongations are more capable of resisting flexure up to appreciable angles without destruction than are metals showing little uniform elongation. In the first category the deformation extends along the greater part of the length of the specimen, and this causes less deformation per unit of cross-section.—L. B.

Study of the Hot Workability of Low Carbon Steel (II). T. Akutagawa, Y. Mishima, E. Asano and A. Suseki. (*Ann. Rep. Eng. Res. Inst., Faculty Eng. Tokyo Univ.*, 1958, **16**, Mar., 49–54). [In Japanese]. The effects of Cu and Sn in 0·08–0·20% C steel were studied by hot bending and hot rolling tests and examination of structure. Concentration occurs at the surfaces and grain boundaries and tends to produce cracking during hot rolling.

Fracture Mechanism of Semi-Brittle Steels in Torsion. J. B. Hunt. (*J. Mech. Phys. Solids*, 1958, **6**, July, 321–326). A pattern observed on certain mild steels fractured in torsion led to investigations which showed a mechanism of tensile failure and sliding in shear.

The Energy Stored in Ingot Iron Deformed by Torsion at 25° C, − 82° C and − 185° C. T. P. Wang and N. Brown. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 53, pp. 30). Energy from 0·3 to 1·1 cals/gm was found to be released in two stages, the first attributed to recovery from deformation and the second and major portion to recrystallization.—E. E. W.

Some Relationships between Torsional Strength and Electron Microstructure in a High Carbon Steel. S. T. Ross, R. P. Sernka and W. E. Jominy. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 46, pp. 28). The torsional yield strength *versus* hardness relationship for quenched and tempered SAE 51100 steel is linear only up to about 57·5 Rc. The same relationship is linear for austempered steel between Rc 53 and Rc 60 and ductile fractures were exhibited. Percarbide films and elongated cementite particles in martensitic needle boundaries were observed in quenched and tempered samples displaying erratic yield strength results and brittle fractures.

Effect of Grain Size and Carbon Content on the Yield Delay-Time of Mild Steel. J. M. Krafft and A. M. Sullivan. (*Trans. A.S.M.*, 1957, **51**, preprint 65, pp. 30). Compression loading was applied to a cylinder for 5 microsec. and held constant for ∼ 600. The time during which the load is supported, if the specimen gives way, is noted as the delay time and is characteristic of materials with an upper yield point. In pure iron the yield point is linked to traces of C or N, it does not occur in single crystals. A similar effect is noted in polycrystalline iron where the grain size has a dominating effect. This is discussed.

Studies on the Lattice Imperfections in Solid Crystals and their Application to the Problems of Cold-working of Metals and Photographic Sensitivity. H. Kanzaki. (*Tokyo Univ. Rep. Inst. Ind. Sci.*, 1957, **6**, Sept., 230–283). [In English]. Experimental studies are reported on the behaviour of phonons, electrons and holes, excitons, vacant sites and interstitial atoms, foreign atoms in the lattice, and dislocations. The usefulness of metals and alloys depends on lattice imperfections and their interactions, mainly of vacancies and interstitials with dislocations. Cold-working is the movement of dislocations under external stress. (29 references).—K. E. J.

Some Observations of Deformation Structures in Hand Impact Tools and on Splinters from Such Tools. A. Hultgren. (*Jenkont. Ann.*, 1958, **142**, (5), 229–245). Local plastic shearing has been observed in used tools. Splinters from beet-hoes are studied, and an unhardened chisel head showed upsetting, but contained no light-etching layers.

A Survey of the Mathematics Available for Describing Fracture. A. E. Scheidegger. (*Can. J. Phys.*, 1958, **36**, Mar., 300–308). Dislocation theory is used to formulate a law of spreading for a crack under various rheological conditions.

The Testing and Properties of Heat-Resisting Materials. (**Central Research Institute of Technology and Engineering*, Vol. 79 of *Ts NIIT Mash Series*, 1957, pp. 214). **On the Mechanism of Diffusion in Solid Metals.** I. L. Mirkin (5–24). **A Study of the Creep and Rupture of Steels in Zones of Stress Concentration.** I. L. Mirkin and I. I. Trunin. (25–45). **The Effect of Temperature Variations on Creep Resistance.** S. I. Matveev and L. P. Trusov. (46–60). **The Effect of Heat Treatment on Relaxation Creep in Austenitic Steels.** I. A. Oding and Z. N. Patropavlovskii. (61–80). **The Effect of Molybdenum on Relaxation Creep in Low-Carbon Pearlitic Steels for Steam Pipelines.** V. Z. Tseitlin. (81–86). **Cast Austenitic Steel with Decreased Sensitivity to Intercrystalline Corrosion.** G. P. Fedortsov-Lutikov and T. S. Griboedova. (87–104). A steel with 15% Ni, 15% Cr, 3% C and Mo, W and Ti is described. **Austenitic Steels for Large Cast Turbine Components.** L. P. Nikitina and A. S. Tereshkovich. (105–129). More tests on the above steel are reported. **A Study of Production Steel Type EI 531.** M. A. Filatova (130–139). **Welded Steam-Pipe Joints in Dissimilar Steels.** E. S. Slepak and M. A. Filatova. (140–148). **Long-Term Relaxation Tests on Spring Steels.** T. I. Volkova. (149–158). **The High Temperature Thermal Conductivities and Electrical Resistivities of Some Heat-Resisting Materials.** V. I. Perova and L. I. Knoroz. (159–174). **The Time Stress Relationship in the Second Stage of Creep.** L. P. Nikitina. (175–188). **The Calculation of Limiting Creep Strength from the Plastic Properties of Materials.** L. P. Nikitina. (189–197). **Study of the Structure of Oxide Films on Heat-Resisting Steels EI.434 and E.I.395.** S. A. Yuganova and B. I. Gorosakov. (198–214). **Table of Compositions of Steels Referred to in the Work.**

Effect of Ageing Cycle on the Properties of an Iron Base Alloy Hardened with Titanium. T. W. Eichelberger. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 21, pp. 34). An ageing treatment has been developed that increases the creep-rupture time for both plain and notch bar specimens, although the notch sensitivity in creep has been greatly reduced. No change has been produced in the room temperature or 1200° F tensile properties.—E. E. W.

Creep Characteristics of Steels for Gas Turbines. C. Roques, C. Dubois and P. Bastien. (*Rev. Mét.*, 1958, **55**, Mar., 227–259). A critical review is presented of creep test procedures and of methods for interpreting the results. Details are given of tests made to assess materials for use in the most important parts of gas turbines. These include more than 30, 5000 h and 10,000 h tests and 12 lasting from 10,000 to 25,000 h. Inspection problems are discussed and the importance of good high-temperature ductility in certain components is stressed.—B. G. B.

Steels for Use in Steam Power Plant Operating above 950° F: Creep, Stress-Relaxation and Metallurgical Properties. N. P. Allen and Sub-Committee J/E. (*Brit. Elect. Allied Ind. Res. Assoc. Tech. Rep.*, 1957, J/T 170, pp. 59).

Operating Experiences with High Temperature Steam Turbine Rotors and Design Improvements in Rotor Blade Fastenings. J. D. Conrad and N. L. Mochel. (*A.S.M.E. Paper No.* 57-PWR-10, 1957, pp. 51). The failure of a rotor in 1955 and its repair and experiences with Cr–Mo–V and Ni–Cr–Mo–V steel rotors are described.

Experience with Chromium–Molybdenum–Vanadium Steel in High Temperature Bolting Applications. R. G. Matters and C. D. Dickinson. (*Trans. A.S.M.E.*, 1958, **80**, Feb., 330–334). Within the past two years Cr–Mo–V bolts have failed in two central station turbines. From an examination of the bolts the cause of failure is analysed and

recommendations to avoid further failures are made.—A. G.

Axial Defects in Cold Drawn Ball Bearing Steel. O. M. Chekhomov, and V. N. Davidyuk. (*Stal'*, 1958, (4), 354). Axial defects are usually detected by examining fractures from both ends of the rods. They are classed as shrinkage and show up as $\sim \frac{1}{2}$ in cracks and are not usually associated with inclusions. There was a decarburized layer at the edge of the defect in 20% of the rejects, in 30% the zone contained slag and in 50% the metal in the region of the defect was completely satisfactory. These defects were attributed to piping, but even with 18% discard were not eliminated, nor with avoidance of pigeon holes. Longitudinal sections suggested that the defects arose from porosity. In a 2·5 t ingot there was porosity extending as much as 3 ft 6 in. into the ingot or two-thirds of the total height. It was decided to increase taper and reduce the ratio of length to central diameter. Taper was increased to 8·72% in the top and 6·65% total. Crystallization then took place from bottom to top. The feeder head was increased to 24·2% of the total weight of liquid metal. These measures reduced defective heats from 28·9% to 13% over a period of years.—R. S.

The Hardness of Metals. M. J. Druyvesteyn and M. A. Meyer. (**Metalen.*, 1952, **7**, (12), 203–206). A thesis. Methods of determination are outlined and evaluated.

A New Standard Hardness Testing Machine. R. S. Marriner and F. C. P. Mason. (*Metallurgia*, 1958, **57**, Jan., 47–51). A description is given of a machine using a 136° pyramid diamond indentor, and built at the N.P.L. to calibrate hardness blocks.—A. G.

Apparatus for Determining the Hardness of Metals at Temperatures up to 3000 F. Elevated Temperature Hardness of Iron, Molybdenum, Tungsten and S-816. S. Semchyshen and C. S. Torgerson. (*Trans. A. S. M.*, 1957, **50**, Preprint 12, pp. 9). An apparatus using a synthetic sapphire pyramid penetrator is described; a purified argon atmosphere protects both the test specimen and the heating element from oxidation. The sensitivity of the apparatus is determined by hardness values for pure iron at temperatures of the $\alpha \rightarrow \gamma$ transformations.—E. E. W.

The Response of an Iron-Base Alloy, Hardened with Titanium, to Various Ageing Times and Temperatures. T. W. Eichelberger. (*Trans. A.S.M.*, 1957, **51**, preprint 60, pp. 29). Ti, Mo and V were studied in the age-hardening of a commercial Ni–Cr–Fe alloy between 1100–1600° F from 1–512 h. Time to reach maximum hardness is shown as a function of temperature.

Stress Conditions for Brittle Fracture of Mild Steel. T. Yokobori, H. Hamamoto and A. Otsuka. (*Nature*, 1958, **181**, June 21, 1719–1720). Torsion tests at liquid air temperature were carried out and neither the maximum tensile stress nor the maximum shear stress conditions were found to apply. Mechanisms are indicated.

The Influence of Sulphur and Oxygen in Causing Red-Shortness of Steel. A. Josefsson, J. Koeneman, and G. Lagerberg. (*JISI*, 1959, **191**, Mar., 240–250). [This issue].

Cleavage Step Formation in Brittle Fracture Propagation. J. M. Berry. (*Trans. A.S.M.*, 1957, **51**, preprint 57, pp. 44). Single crystals of Si–Fe were cleaved in the [110] direction by driving in a wedge. Temperatures from − 196° to + 25° C seemed to have no effect on the propagation mechanism. Cleavage steps were examined and found to become smaller as distance from the notch increased. The role of plastic deformation is discussed.

Influence of Internal Stresses on the Formation of Flakes. I. E. Brainin, V. A. Kharchenko and A. I. Kondrashov. (*Stal'*, 1958, (4), 342–348). Forged Cr–Ni steel with 0·39% C, 0·62% Mn, 0·22% Si 0·65% Cr and 1·2% Ni was used and it was confirmed that flaking was due to the simultaneous action of H_2 and tensile stresses. In the outer zone where H_2 is negligible, flakes do not occur even under high stresses and even very small compressive stresses can prevent flaking in the centre of the zone of maximum hydrogen content. Large forgings must be cooled slowly after annealing to prevent flaking.

Brittle to Ductile Transition Temperatures of Binary Chromium Base Alloys. E. P. Abrahamson jun. and N. J. Grant. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 14, pp. 17). The transition temperature for brittle fracture of Cr alloys with up to 30% of various elements has been studied. There is a correlation between the rate of transition temperature change and the election configuration of the solute element including iron.—E. E. W.

The Initiation of Brittle Fracture in Mild Steel. J. A. Hendrickson, D. S. Wood and D. S. Clark. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 28, pp. 22). The results of tests indicate that the initiation is governed by a critical tensile stress which is independent of temperature or rate of loading. It should be possible to predict the conditions under which brittle fracture will occur in specimens having any notch geometry, provided the influence of temperature and stress rate on the yield stress and the true fracture stress are known.—E. E. W.

Carbide Precipitation and Brittleness in Austenitic Stainless Steel. A. Kramer and W. M. Baldwin, jun. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 32, pp. 18). The tensile ductility of steels, AISI Types 304 ELC, 304 and 302 in the annealed condition dropped as the strain rate was increased, the drop being greatest at room temperature. There was a maximum at room temperature with low strain rates but it increased steadily with temperature at high strain rates. Magnetic measurements of the martensite formed during deformation confirmed earlier results. In the sensitized material the percentage of sensitization was a function of the carbon content. Carbide embrittlement showed primarily in the range of low temperatures at low strain rates.

Discussion of Temper Brittleness: Part II. V. D. Sadovskii. (*Metallov. Obra. Met.*, 1957, June, 31–42). A review of the theory with 58 refs.

Brittle Fracture. G. M. Boyd. (*Metalen*, 1958, **13**, June 15, 200–205; June 30th, 224–228). [In English]. Fractures of various kinds are described and illustrated and the patterns formed are discussed. The initiation of brittle fractures is considered. **The Problem as it Exists Today.** This section deals with the effect of temperature on propensity to brittle fracture, relation of toughness to strength, the influence of welding stresses on the incidence of brittle fracture and remedial measures.

A Study of the Role of Carbon in Temper Embrittlement. E. B. Mikus and C. A. Siebert. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 39, pp. 19). Electron microscopy and autoradiography using ^{14}C were used on a 3140 steel. Isothermal heat treatments up to 500 h were investigated. A number of theories was evaluated and a new mechanism proposed based on the development of strained prior austenite boundaries during the embrittling heat treatment.—E. E. W.

The Effect of Aluminium Nitride on the Brittle Property of Cast Steel. D. K. Butakov. (*Stal'*, 1958, (5), 457–463). Vacuum casts of steel confirmed that one cause of intergranular brittleness is AlN precipitation at austenite boundaries. To eliminate this both N_2 and Al should be kept to a minimum by correct slag procedure to isolate the metal from the furnace atmosphere with a slag of low gas permeability. Rapid cooling and homogenizing of the cast steel and forging and rolling greatly reduce the harmful effect of the precipitate.—R. S.

Brittle Fracture in Steel as Related to Flash-Welded Line Pipe. M. A. Scheil, G. E. Fratcher, S. L. Henry and E. H. Uecker. (*Eng. J.*, 1958, **41**, Mar., 59–63). Manganese steel with 0·2–0·3% C is considered and metallurgical concepts and design factors are reviewed. A curve showing stress and temperature conditions for crack propagation is obtained and the nil-ductility transition temperature is derived.

Machine-Tool Materials: Coefficients of Flat-Surface Friction. A. O. Schmidt and E. J. Weiter. (*Foundry Trade J.*, 1958, **104**, Apr. 3, 381–383). Steel, hardened and ground and ground and hand-scraped cast iron were used as slide materials with sliders of cast iron, bearing bronze and non-metallics and friction, rate of wear and effects of lubrication were noted.

The Intrinsic Variables Affecting the Stick-Slip Process. E. Rabinowicz. (*Proc. Phys. Soc.*, 1958, **71**, Apr. 1, 668–675).

New Coefficients Predict Wear of Mata Parts. E. Rabinowicz. (*Prod. Eng.*, 1958, **29**, June 23, 71–73). Wear processes are classified as adhesive, abrasive, corrosive and surface fatigue. The calculation of the first and most important is developed and a simple formula for predicting wear is given in terms of a coefficient of wear, and methods of determining this are shown. Estimation of wear of the other three types is also discussed and the cases of fixed gauges and wear in wire drawing are worked as examples.

The Mechanical Wear of Metals. W. Hirst. (*Brit. J. Appl. Phys.*, 1958, **9**, Apr., 125–132). A review. The design of experiments, laws of unlubricated wear and theories of wear and lubrication are discussed. (28 refs.).

Factors Influencing the Resistance of Steel Castings to High Stress Abrasion. T. E. Norman. (*Mod. Castings*, 1958, **33**, May, 89–98). A short time test procedure has made it possible to study the effect of a large number of variables on abrasion resistance of ball mill liners. A 'lean-alloy' high carbon austenite is capable of better abrasion resistance than the conventional 12% Mn steel.—A. G.

Investigation of the Condition of Stress of Surface Layers of Solid Bodies Rubbing Against One Another when Slipping To and Fro. K. V. Savitskii and Yu. P. Geraskevich. (*Fiz. Met. Metalloved.*, 1957, **4**, (3), 519–526). The experimental results set out in this article show that the alternating direction of slipping during friction of metallic parts leads to an appreciable reduction in resistance to deformation of the outer layers and to softening. The results also justify the conclusion that the alternation in slipping does not lead to any supplementary accumulation of dislocations in the deformed lattice.—L. B.

Intense Magnetic-Field Apparatus for Constitutional Investigation of Steels. A. Salmont, J. Dedieu and P. Bastien. (*Rev. Met.*, 1957, **54**, Dec., 897–909). The apparatus is designed to measure the intensity of magnetization of specimens approximately 100 mm long and 6 mm dia. between 20 and 700° C and in a magnetic field between 100 and 3500 oersteds. The results of preliminary tests are described and illustrate the scope of the apparatus.

The Transverse Magnetization of Iron-Silicon Alloy. V. V. Druzhinin and Yu. A. Lazarev. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 164–168). Results are given of investigations of the transverse magnetostriction of Fe-Si alloys containing from 0·4 to 7% Si. The measurements were carried out with wire devices without fastening them to the specimens. The latter were made of hot and cold rolled steels. The magnetostriction was measured as a function of the magnetizability of the specimen. The results are plotted on graphs both for the longitudinal and transverse magnetostriction for various steels.

Rapid Method of Identification of Alloys and Special Steels. (*J. Four Elect.*, 1957, **62**, Nov.-Dec., 209–210). A description is given of the possibilities and limitations of the "Electro-Test" method of analysis, using special reagents and electrodes. It is claimed that the method will identify and determine the concentrations of certain elements and alloys with a relative error of ± 10–20%.

Influence of Recrystallisation on the Texture of Low-Carbon and Dynamo Steels. K. V. Grigorov, G. P. Blokhin and M. Ya. Zakutner. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 150–153). The magnetometric method was used in the investigation of the change of texture of cold rolled low-carbon and dynamo steels in the $\alpha \rightleftarrows \gamma$ transformation. Under slight deformation of low-carbon and dynamo steels the character of the texture changes with appreciable weakening in its definition.—L. B.

Selection of the Optimum Geometrical

Dimensions of Attached Electro-magnetic Coercive Force Meters Intended for Controlling the Quality of the Thermal and Chemico-thermal Treatment of Steel and Iron Components. M. N. Mikheev. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 44–52). The article shows that in using suitable coercive force meters, with attached electro-magnets, it is possible to carry out in addition to control throughout of the thermal treatment, the control in depth of the surface layers on the steel components in all the ranges of thickness met with in practice, from the thin nitrided and cemented layers amounting to fractions of a mm to hardened layers of any thickness, on components of any size and shape.—L. B.

The State of the Atoms in the Alloys of the Transition Elements. I. Ya. Dekhtyar. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 17–22). The study of the magnetic properties of transition elements is one way of obtaining their electronic structure. The method of neutron analysis should, in principle, make it possible to gain information from the dispersion regarding the structure of the outer electron shells of the various atoms and therefore of the atoms themselves. The value of the magnetic moment of the atom permits the determination of its ionic state by means of the coefficient q of the filling-up of the d-vacancies. If d_0 and s be the numbers of d and s electrons in the atom and x the coefficient characterizing the stages of interaction between the d and s electrons, the average magnetic moment is

$$m = d_0 + xs$$

and

$$\frac{d_0 - m}{d_0} = -x\frac{s}{d_0}$$

The left-hand side represents the coefficient q. x has been calculated for Fe, Co and Ni respectively as 0·94, 0·65, and 0·7, whence q for the same elements is 0·47, 0·44 and 0·7.

On the Influence of Elastic Stresses on the Electro-magnetic Properties of Electro-technical Steels. A. D. Sokolov. (*Fiz. Met. Metalloved.*, 1957, **4**, (3), 555–558). Experimental results confirm the appreciable influence which the straightening of the uneven shape of sheets of electro-technical steels has on their electro-magnetic properties. It follows that this straightening is necessary and that the surface of the sheets must be absolutely flat to improve their magnetic properties and to facilitate the production of flat parts.—L. B.

Effect of Manganese on the Curie Point of Cementite. E. C. Roberts. (*Trans. A. S. M.*, 1957, **50**, Preprint 11, pp. 21). The % Mn in the cementite of an annealed steel is a function of both Mn and C of the steel. Empirical equations are given.—E. E. W.

Non-destructive Testing of Rotors and Other Parts of Water Turbines. J. Thouvenin. (*Rev. Met.*, 1957, **54**, Dec., 945–959). Visual, ultrasonic, magnetic, penetrant and gamma radiography methods of testing are described. The information obtainable from each method is considered. Details are given of the practical operation of each technique and of the importance of non-destructive testing of water-turbine parts.—R. G. B.

Basic Data: Incoloy "901" Nickel Iron Chromium Alloy. (*Internat. Nickel Co. leaflet*, pp. 3).

A Portable Magnetizer for Magnetic Crack Detection. J. W. Walley. (*Metro-Vick. Gaz.*, 1958, **29**, Apr., 118–121).

Magnetic Analysis of Phase Changes Produced in Tempering a High-Carbon Steel. M. Mentser. (*Trans. A.S.M.*, 1957, **51**, preprint 66, pp. 36). Carbide phases were examined in a quench-hardened steel. Hexagonal close-packed carbide was identified by its point of magnetic inflection at ~ 380° C. It is shown to be formed from retained austenite in the second stage of tempering at 230° C or lower. Thus bainite is initially an aggregate of ferrite and hexagonal carbide. The same sequence occurs in tempering martensite. Transformation to cementite occurs mainly in the third stage. No evidence of Hägg carbide was found.

The Use of Non-destructive Testing on Steel Castings for Elevated Temperature Service. (*Mech. Eng.*, 1958, **80**, April, 66–69). Methods of non-destructive testing, including stereo-radiography, magnetic particle examination and ultrasonic inspection are described.—A. G.

Theory of the Shubnikov de Haas Effect. E. M. Lifshits and A. M. Kosevich. (*Phys. Chem. Solids*, 1958, **4**, (1–2), 1–10). The conductivity theory of Lifshits is extended to determine quantum corrections containing conductivity oscillations. **Quantum Theory of the Electrical Conductivity of Metals in a Magnetic Field.** E. M. Lifshits. (*Phys. Chem. Solids*, 1958, **4**, (1–2), 11–18). Mathematical.

Advantages and Limits of Non-destructive Testing. K. Krainer. (*Nondestr. Test.*, 1958, **16**, Mar.-Apr., 96–102). Choice of method, including economic factors, is discussed. Applications are discussed in terms of substitution for destructive methods, anticipating tests usually made at later stages in finishing, and degree of hazard involved in the kind of defect sought.

A Critical Survey of the General Limitations of the Non-destructive Testing Field. D. W. Ballard. (*Nondestr. Test.*, 1958, **16**, Mar.-Apr., 103–112). (26 refs. and bibliography).

The Relative Advantage and Limitation of Non-destructive Testing Methods. L. van. Ouwerkerk. (*Nondestr. Test.*, 1958, **16**, Mar.-Apr., 113–127). Introduction and discussion of radiographic methods. **Restrictions on Radiography with High Energy.** H. den Hartog. **On the Problem of the Calibration of X-Ray Equipment.** G. Moravia. **Ultrasonics:** Rontgen Technische Dienst. **Magnetic and Penetrant Inspection.** A. de Sterke. **Black Magic or Technical Science.** B. Schuil. **Definition of Non-destructive Testing.** G. Moravia. **Central Institution.** A. Junghem. A good deal of the discussion is concerned with welding.

Discussion of the Relative Advantages and Limitations of Non-destructive Testing Methods. H. Kihara. (*Nondestr. Test.*, 1958, **16**, Mar.-Apr., 127–132). A. F. Cota. (132–134). **Summary of Session.** R. A. Pulk. (134–136).

Suggestions for Standardization and Development of the Classical Methods of Non-destructive Testing. H. W. R. Seifert. (*Nondestr. Test.*, 1958, **16**, Mar.-Apr., 138–142). **Recommendations for Technical Development and Standardization.** O. Masi. (143–145). R. B. Oliver. (145–148). W. A. Felix. (148–149). D. C. Erdman. (150–152). **Summary of the Session.** R. A. Palk. (152).

Ultrasonic Detection of Thin Laminar Inclusions. S. Serabian and C. D. Moriarty. (*A.S.M.E. paper No.* 57-PWR-11, 1957, Oct., pp. 14). Inclusions in large turbo-generator rotor forgings are studied and findings are related to thickness and composition.

The Cathode Ray Tube Type Ultrasonic Thickness Gauge and Its Application to Non-Destructive Testing. N. Niwa. (*Report of the Institute of Industrial Science: University of Tokyo*, 1958, **7**, Feb., 1–67). [In Japanese]. Examination of corroded plates and flaw detection are described. The gauge and its scaling system and probes are described in detail.

The Ultrasonic Control of Materials. P. Hemardinquer. (*Rev. Gén. Mée.*, 1958, **42**, Jan., 47–50). A brief outline is given of ultrasonic instruments and techniques for the detection of defects and measurement of thickness.—L. D. B.

Image Quality in the Radiography of Heavy Sections of Steel Using High Energy Radiation. G. Chanty and E. Mencarelli. (*Rev. Mét.*, 1958, **55**, Mar., 218–226). A study has been made of the exposure time and image quality obtained in radiographing steel over 100 mm thick using high-energy radiation sources such as the 2000 kV pulsating-voltage G.E.C. generator and the 31-MeV Brown Boveri betatron. Graphs showing image quality as a function of the thickness are given. A comparison is made of results obtained with ^{60}Co radiation on 100 and 200 mm thick steel.

The Metallographic Application of X-Ray Scanning Microanalysis. D. A. Melford and P. Duncumb. (*Metallurgia*, 1958, **57**, March, 159–161). A scanning version of the Castaing technique for determining the composition of a minute area of metal is described. Close correlation is obtained between the new instrument and optical micrographs.—A. G.

Comparative Measurements of the Vapour Pressures of Chromium and Iron by the Rate of Vaporisation *in vacuo*. V. D. Burlakov. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 91–101). Preliminary calculations based on the latest data on vapour tensions suggest that by distillation *in vacuo* it may be possible to purify Cr from small admixtures of Fe. By measuring the rate of vaporization from the bulk of the volatilized layer, the relative volatility of Fe and Cr can be determined within the temperature range 1350–1450° K. with the simultaneous vaporization of the condensed layers of these metals. On the strength of the experimental results conclusions are reached that the difference in the rates of vaporization of Cr and Fe is insufficient, taking into account, also, a diminution of the rate of vaporization of Cr due to the change of structure on its surface. This explains the inefficient purification of Cr from Fe admixtures, when attempted in a vacuum.

The High Temperature Properties of 18–12–1 Cr–Ni–Nb Steel. A Summary of British Data. W. H. Bailey, M. G. Gemmill, H. W. Kirkby, J. D. Murray, E. A. Jenkinson and A. I. Smith. (*Brit. Elect. Allied Ind. Res. Assoc. Refs.*, 1956, J/T 169, pp. 22). Tensile and creep properties are given.

A New Method for Measuring High-Temperature Stresses with Strain-Sensitive Ceramic-Base Coatings. F. B. Stern. (*Mach. Design*, 1958, **30**, May 29, 147–149). Coatings giving accurate stress measurements in the range — 50 to 600° F are described. A selection chart is given depending upon the coefficient of expansion of the metal.

A Magnetic Method of Detecting Diffusion in Metals. A. S. Mil'ner and K. V. Feodos'eva. (*Fiz. Met.*, 1956, **3**, (3), 483–485). The Ni–Cu system was examined by evaporating Ni on to a cold Cu plate and examining change in magnetic properties in an apparatus described elsewhere.

Radiographic Investigation of the Diffusion of Carbon in Iron Alloys. A. S. Zav'yalov and B. I. Bruk. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 127–136). By means of the radioactive isotope ^{14}C, the diffusion of carbon in iron alloys with Cr, W, Si and Mo was investigated by auto-radiography. When the concentration of the alloy elements and carbon at the given temperature does not exceed their limiting solubility in iron, the carbon and the alloy elements are diffused relatively uniformly through the whole volume of the grain. When the concentration of the carbide-forming elements exceeds the limiting solubility, the boundaries will enrich themselves in these elements and will therefore lose carbon.—L. B.

Superstructure and Temperature Dependence of the Energy of the Magnetic Anisotropy of Nickel Iron Alloys. I. M. Puzei. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1094–1104). In the work described the temperature dependence of the energy of anisotropy of binary Fe–Ni alloys and also the dependence of this energy for permalloy-type alloys with Mo, Cr and Cu on the degree of order were studied. Single-crystal spherical specimens prepared by slow cooling of the melt in a vacuum were used, chemical, X-ray and neutron-diffraction investigations being carried out. The specimens were subjected to a variety of heat treatments. The author describes his method for producing thermally stabilized permalloys and gives comparative permeability data for a Mo permalloy.—S. K.

On the Role of Closure Regions in Technical Magnetization Processes. Ya. S. Shur, V. R. Abel's and V. A. Zaikova. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1162–1167). In this work the nature of the closure domains of a 4·0% Si iron was studied with the aid of powder patterns. The form of the region and its connection with the natural crystallographic anisotropy, the dependence of the form of the regions on specimen thickness, changes in the form on elastic extension of the specimen,

on growth of field strength and on decrease of field strength are considered, as well as the magnetic structure in the state of residual magnetization. Details of the experimental method are not given.—S. K.

The Domain Structure of Ferromagnetics at High Temperatures. Ya. Katszer. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1170–1175). Domain structures of a magnetite single crystal at temperatures from room to 550° C and of cobalt to 680° C are shown. The structures are discussed and it is suggested that for a fully quantitative picture the anisotropy constants over the same temperature ranges should be found.—S. K.

Direct Observations of the Domains of a Ferromagnetic with the Aid of a Secondary-Emission Electron Microscope and an Electron Mirror. G. V. Spivak, N. G. Kanavina, I. S. Shtnikova, I. N. Prilezhaeva, T. N. Dombrovskaya and V. K. Azovtsev. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1177–1182). A method is described in which, with the aid of electron beams, a direct image is obtained both of the domains of a ferromagnetic and of the magnetization on the surface of the specimen. The method is based on the idea that it is possible to produce electron-optical contrast, and hence to see regions of magnetic heterogeneity, as these heterogeneities act as magnetic micro-lenses set in the flat conducting surface. Examples of the effects visualized are shown and discussed.—S. K.

On the Conditions of Demagnetisation of Test-Pieces of Electrotechnical Steels. V. V. Druzhinin and Yu. A. Lazarev. (*Zavods. Lab.*, 1957, (12), 1451–1454). [In Russian]. Five types of electrotechnical steels have been investigated and it has been shown that by changing the time of demagnetization from 30 to 120 sec the value of the magnetic induction fluctuated within 2%. In further experiments with a fixed time interval of 30 sec for demagnetization, the measurements of the magnetic induction was done 10 min after demagnetization and the results are tabulated in detail.—L. B.

Electrical Resistance and its Change in a Strong Magnetic Field for Iron–Nickel Alloys in the Low-Temperature (14–77° K) Region. E. I. Kondorskii and I. E. Ozhigov. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1131–1132). The work briefly reported had as its object the study of the galvano-magnetic effect $\Delta R_0/R$ and related parameters in a longitudinal magnetic field for iron–nickel alloys (40–100% Ni) in the temperature range 14–90° K.—S. K.

Non-Destructive Testing of Metallic Materials by Means of an Electromagnetic Induction Method. F. Förster. (*Metall*, 1957, **11**, Oct., 837–846). This is a survey of theoretical and experimental knowledge about the eddy-current technique of testing, and its applications. All problems solved theoretically or experimentally are listed in a table, together with applications, some examples of which we also discussed. (54 references).

Effect of Aluminium on Specific Losses of Transformer Steel. N. F. Dubrov. (*Stal'*, 1958, (3), 246–248). It is shown that, in the production of transformer steel sheets which are to be subjected to high temperature annealing, it is necessary to avoid the introduction of Al into the metal even in small quantities. Al, therefore, must not be used for deoxidizing these steels and the absolutely minimum amounts must be used for alloying purposes.—S. S.

Organized for Electronics. (*Steel*, 1958, **142**, Mar. 24, 112, 115). A new department set up by Weirton Steel Co. is described and a list of the installations, with brief notes, is given.

A New Method of Measuring Thickness or the Speed of Sound. L. Niklas. (**Z. Metallk.*, 1958, **49**, Mar., 152–155). It has been pointed out that the measurement of wall thickness by means of ultrasonic echo-sounding instruments becomes inaccurate if only a few echoes can be utilized, due to absorption or other reasons. In these cases accuracy can be increased by using the harmonic waves of the echo frequency, to determine either thickness or sonic speeds.—L. D. B.

The Velocity of Sound as a Characteristic Value for Assessing the Properties of Cast Iron. R. Ziegler and R. Gerstner. (*Giesserei*, 1958, **45**, April 10, 185–193). It is shown by a series of investigations that the velocity of sound in cast iron, which can be measured easily and rapidly, can be used to determine the following properties: modulus of elasticity, amount and size of the graphite, degree of saturation, tensile strength etc. It is suggested that the technique could be applied to other materials.

Detection of Defects in Sheet Iron. (*Tech. Indust.*, 1957, **35**, 1617–1619). An outline is given of ultrasonic, electrical and magnetic methods available for the non-destructive testing of steel sheet for defects.—L. D. B.

Ultrasonic Testing of Materials. P. Hernardinquer. (*Rev. Gen. Méc.*, 1957, **41**, Nov., 491–494). Two methods for the ultrasonic testing of materials are described with special reference to the detection of defects and inclusions in welds. The methods can be applied to the testing of non-metallic materials.—R. F.

Ultrasonic Material Testing. F. Wolters. (*Lastechn.*, 1958, **24**, Feb., 20–22). [In Dutch]. The article describes a direct reflection method apparatus consisting of a cathode-ray oscillograph and tube for detecting defects in materials. Reference is made to its application for finding faults in different kinds of welds with remarks on the type of defect to be expected from the shape of the reflection curve shewn on the instrument screen.—F. R. B.

Determination of the Radiographic Values of the Elastic Constants of Cold Elongated Armco Iron and Chrome–Molybdenum Steel. E. Macherauch and P. Müller. (*Arch. Eisenhüt.*, 1958, **29**, Apr., 257–260). Two possibilities, arising from the theory of elasticity, for determining the elastic constants by X-ray radiography are discussed in detail. The experiments were conducted on specimens of Armco iron and Cr–Mo steel with 1·0% Cr and 0·2% Mo, under uniaxial loading. In accordance with the theory, no dependence of the elastic constants on the direction of measurement was found, or on the applied stress.

The Use of Proportional Counters and Pulse Height Discrimination in the Counter Goniometer. F. Bollenrath and H. Krings. (*Arch. Eisenhüt.*, 1958, **29**, Mar., 189–191). The advantages to be gained in the use of pulse height discrimination in Cr–Ni steel with the counter goniometer are discussed.

Non-Destructive Materials Testing with the Aid of Radioactive Isotopes. E. Schiebold and E. Becker. (*Technik*, 1958, **13**, May, 337–343). The economic importance of non-destructive testing is emphasized, the production of radioactive isotopes and the technique of their use in testing are outlined, and γ- and X-ray investigations are compared.—L. D. B.

Autoradiography in the Steel Industry. L. Simon. (*Hutnik*, 1958, **8**, March, 74–78). The basis, importance and application of autoradiography in metallurgy, and the progress of the science in Czechoslovakia are outlined. Photographic materials, the activation of samples and their preparation are described. Examples of autoradiographs are given, and the results of their study are indicated.

Determination of the Vapour Pressure of Iron Over Austenite. E. Z. Vintaikin. (*Doklady A.N.*, 1957, **117**, (4), 632–634). The apparatus and methods of study of pure iron and Fe–C alloys containing 2·7 and 4·3 atomic % C at 1150–1350° C, are described. In the case of pure iron, a linear pressure-temperature function is observed, corresponding to a formula (in dyn/cm²)

$$\log p = -\frac{20630}{T} + 12{\cdot}70$$

In the case of Fe–C alloys at lower temperatures the log p values are situated slightly above the straight line, which is due to the recrystillization of austenite grains at the $\alpha \rightarrow \gamma$ transformation. The calculated heats of sublimation vary but little with carbon contents.—S. L. T.

Chromium Vapour-Pressure Over Solid Chromium Iron Alloys. E. Z. Vintaikin. (*Doklady A.N.*, 1958, **118**, (5), 977–979). The vapour pressure of Cr over Cr–Fe alloys in the range 1100–1400° C was measured by the effusion method of Knudsen with radiometric determination of the quantities of Cr deposited on targets. At the same time the thermodynamic activity and heat of solution of Cr were calculated. In these alloys there is a positive heat of mixing and thereupon the solid solution Cr–Fe has a tendency towards exsolution and a tendency for the development of brittleness near 475° C may be the consequence of this. One may suppose that at 475° C α-solution is either transformed into α-phase or is transformed into two solid solutions.—S. L. T.

The Lorentz Constant for Steels. R. E. Krzhizhanovskii. (*Zhur. Tekhn. Fiz.*, 1958, **28**, (1), 202–206). Heat transfer in metals is well known to be effected by electrons and the vibrations of the lattice atoms. Lorentz's constant for steels appears as a parameter related to temperature and composition, but differently related for different types of steel. The investigations detailed in the article cover carbon steels and Cr–Ni alloys and determine the influences of chemical composition and structure.—L. B.

The Behaviour of Steel at Elevated Temperatures: A Review of the Literature Published in 1956. A. Krisch. (*Stahl u. Eisen*, 1958, **78**, Jan. 23, 104–109). The author deals with the change of the elastic constants, hot-drawing and torsion tests, equipment for creep testing, creep properties of various steels, creep theories, and the effect of multi-axial stress and notch effects.—T. G.

Study of Deflection under Load at High Temperature. R. Fourneau. (*Rev. Univ. Min.*, 1957, 9th series, **13**, Oct., 650–663). The results of attempts to devise a European standard test to measure the deflection under load of refractory materials at elevated temperatures are described. A review of methods in use in 7 countries is given in tabular form.—B. G. B.

Research on the Deformation of Steels at Elevated Temperatures. C. Rossard and P. Blain. (*Pub. Inst. Rech. Sid.*, 1957, Series A, No. 174, Oct., 1–88). The results of a comprehensive series of torsion tests under load at high temperatures are described. Tests were carried out between 900 and 1200° C at torsion rates between 0·1 and 1000 r.p.m. Three types of steel were studied in detail; a 0·25% C, a 18–8 stainless and a 25% Cr ferritic. The apparatus is described.—B. G. B.

Study of Heat-resisting Steel. XIII. E. Asano. (*Tetsu-to-Hagane*, 1957, **43**, Dec., 1318–1325). [In Japanese]. Results of X-ray diffraction and other analyses indicate that the precipitated particles in Timken 16–25–6 are M_6C, $(Fe, Cr)_{23}C_6$ and $CrMoN_2$. In the alloy containing Ti, M_2Ti (probably Ni_2Ti), M_6C and $M_{23}C_6$ were found.—K. E. J.

Adaptability of 5% Cr-containing Steel for Heat-resisting Applications. S. Koshiba and T. Kunou. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 142–145). [In Japanese]. Results from DAC and DBC die steels showed their suitability for use as heat-resisting steels at temp. up to 600° C.—K. E. J.

A Study of the Behaviour of Nodular Cast Irons Alloyed with Silicon, at High Temperatures. T. Dumitrescu, M. Nicolaid and P. Iheseu. (*Rev. Mét. Bucarest*, 1956, **1**, 33–53). [In English]. Samples were melted, nodulized and alloyed in the ladle with ferrosilicon at 1320–1330°, and cast in a dry sand mould at 1280–1300° C. Compositions, microstructures, hardness, tensile strength and elongation, transverse strength and deflection, machinability, dilatometric measurements and resistance to oxidation were determined. Up to 4·5% Si the irons were resistant to oxidation up to 850°, have good dimensional stability, high strength and high machinability. Above 4·5% Si they resist oxidation up to 950° C have greater strength but less tenacity and are more difficult to machine.

Bibliography on Low Temperature Characteristics of Steels 1904–1954. K. Janis. (*Publication of the International Co. Inc., New York*, pp. 65). Contains 564 refs. and an author index. Entries in chronological order.

pearlitic and austenitic cast steels, but 12%

(June 324–325, 351). A brief review of types

diagram. This is confirmed by observations

Experimental Difficulties in the Measurement of Self-diffusivity During Compressive Creep. N. Ujiiye, B. L. Averbach, M. Cohen and V. Griffiths. (*Acta Met.*, 1958, **6**, Jan., 68). Errors have been recognized in a method of measuring the coefficient of self-diffusion of iron under compressive creep which involves measuring the change of activity in a plated layer of ^{59}Fe. It has been found that, under creep conditions, self-diffusion is more rapid in the electrodeposit than in bulk.—A. D. H.

The Influence of Chromium, Molybdenum and Tungsten on the Self-diffusion of Iron in Dilute α-Solid Solutions. J. B. Borovskii, K. P. Gurov and Yu. G. Miller. (*Doklady A.N.*, 1958, **118**, (2), 280–283). Six alloys of iron with Cr, Mo and W were prepared with the content of the second component varying from ~ 0·1 to 4 atomic %. Small plates of these alloys were covered electrolytically with a thin layer of ^{59}Fe and the samples were subjected to annealing at 772°, 831° and 898° C after which the coefficients of self-diffusion of iron were measured and plotted against the percentages of the second component. The nature of these curves and theoretical deductions are discussed.—S. I. T.

Preferential Diffusion of Radioactive Iron in Alpha Iron Grain Boundaries and Its Relation with the Structure of Grain Boundaries. C. Leymonie and P. Lacombe. (*Rev. Mét.*, 1957, **54**, Sept., 653–662). A thin layer of radioactive ^{59}Fe and ^{55}Fe is electroplated on iron samples of different purity. Samples are heated in an atmosphere of H_2 or A. Successive layers are electrolytically removed and after each dissolution an autoradiograph is obtained. By examination of the autoradiographs the diffusion appears preferentially in the grain boundaries at low temperatures. Results show that diffusion may be considered only above 850° C as a pure volume diffusion. The penetration of radioactive iron into the grain boundaries depends on the five geometric parameters which define them.—B. G. B.

Methods of Study and Factors Influencing Intergranular Autodiffusion in Metals. G. Cizeron. (*Mét. Corr. Ind.*, 1957, **32**, Sept., 315–332). A comprehensive review of this subject is presented. Grain boundary structure and energy are first considered and this is followed by an assessment of the methods available for studying this type of diffusion. The results obtained by a number of authors are reported and discussed. (59 references).

Method of Investigating the Effect of Pressure and Deformation on the Self-Diffusion of Iron. T. I. Gudkova, V. S. Gorbatov, S. Z. Bokshtein, A. A. Zhukhovitskii and S. T. Kishkin. (*Zavods. Lab.*, 1957, (12), 1438–1439). [In Russian]. A special apparatus was evolved, a description of which is given, which permits the investigation *in vacuo*, in test specimens, of the annealing diffusion under the influence of tensile stresses, in the elastic zone as well as in various stages of plastic deformation.—L. H.

The Diffusion of Carbon in Titanium Containing Gamma Iron. J. Prohászka. (*Koh. Lapok*, 1957, **12**, July, 269–275). A method is described for determining the diffusion of C in Ti containing γ-iron. The method consists of heating butt welded high carbon + low carbon titanium steel specimens between 1000–1200° C, and afterwards carrying out C analysis of layers within ± 10 cm of the weld. It was found that the Ti decreases the diffusion coefficient of carbon.—P. K.

Diffusion of Hydrogen through Iron Sheets in the Temperature Range 20–90° C. W. Raczynski. (*Arch. Hutn.*, 1958, **3**, (1), 59–78). Dependence of cathodic hydrogen diffusion rate or current density was examined and the limiting rate at which it is independent was found. Sheets < 0·9 mm thick give constants which are too low, probably owing to surface effects. The order for iron in thicker sheets was ~ 10^{-6} cm^2/sec. Activation energies were calculated.

Hydrogen in Iron. H. Taxhet. (*Stahl u. Eisen*, 1958, **78**, Jan. 9, 50–52). The author reports unpublished work carried out by Prof. S. Yanagisawa at Tokio University on the effects of H_2 in iron with a modified conventional vacuum-fusion method for the estimation of traces of H_2. He describes two solution-mechanisms for H_2 in iron and deals at length with the effects of dissolved and diffused H_2. Diffusion coefficients are given in a table from 593°–1049° C. Fick's law is applied to the diffusion of H_2 in iron, activation energies of 12,600 cal./g.-atom for γ-iron and of 7220 cal./g.-atom for α-iron were found. Removal of H_2 from metals is dealt with briefly and—finally—the effects of absorbed H_2 on the electrical and magnetic properties of metals, including Ni, are discussed.—T. G.

Gases in Steel and Iron Alloys. H. Feichtinger, J. Gremminger, H. Bächtold and D. Manderson. (*Berg-Hütten. Monatsh.*, 1957, **102**, Oct., 257–271). The vacuum-fusion equipment and analytical apparatus used are described. The gases evolved as the temperature is raised in steps are analysed separately and the progress of gas evolution is registered on a "gas evologram." Equipment for separating non-metallic inclusions on a continuous routine basis is described. (116 references).—R. P.

The Calculation of the Solubility of Nitrogen in Liquid Iron Alloys. M. G. Frohberg. (*Stahl u. Eisen*, 1958, **78**, Apr. 3, 431–432). The graphical method of C. W. Sherman and J. Chipman (*Trans. A.I.M.M.E.*, 1952, **194**, 597) is explained and an example of the calculation of the nitrogen content discussed.

Activities of Mn and C in Molten Fe–Mn–C Alloys. M. Ohtani. (*Tetsu-to-Hagane*, 1957, **43**, Nov., 1211–1215). [In Japanese]. Solubility measurements and e.m.f. measurements in a concentration cell were made for Fe–Mn–C melts containing up to 49% Mn at 1530 ± 10° C. Fe–Mn melts obey Raoult's law, but show a gradual negative deviation on adding C. The effect of C on the activity coeff. of Mn, and vice versa, are discussed. The effect of Mn on the activity coeff. of C is about one-third that of Cr. (12 references).—K. E. J.

Heat Resistance and Relaxation Stability of Chromium–Vanadium and Chromium–Tungsten–Vanadium Structural Steels. L. Ya. Liberman and A. V. Boeva. (*Metall. Obra. Met.*, 1956, (4), 2–10). This investigation obtained data regarding the influence of V, W and C on the tendency to temper brittleness, resistance to creep, duration of this resistance and to relaxation strength. The Cr–V steels show a maximum tendency to temper- and hot-brittleness with a 0·5% V. Resistance to creep, duration of resistance and relaxation strength increase up to 1% V.—L. H.

The Effect of Titanium on the Properties of Carburizing Steels. N. Hajto. (*Koh. Lapok*, 1957, **12**, Jan.–Feb., 3–14). The author reports the mechanical properties of the case and core of carburized and afterwards variously heat-treated Mn–Ti steels with the chemical composition 0·12–0·26% C, 1–2% Mn and 0·1–2·0% Ti. Based on these results he suggests the standardization of such steels with 0·1% Ti content. These steels can be carburized at 920° C and give satisfactory mechanical properties, even in the transverse direction, after a simple oil hardening from the carburizing temperature, without any further heat treatment.—P. K.

Production and Properties of Boron-Containing Non-Ageing Steel. Kh. Levinzon and D. Ditvinenko. (*Stal'*, 1958, (3), 249–252).

American Research on Boron Steels. A. Roos. (*Mét. Constr. Mécan.*, 1957, **89**, Dec., 1015–1019). Boron does not change the microstructure of steels but it improves the suitability of the metal for tempering and avoids the draw-backs of ageing. Boron steels are suitable for spring steel, steels for cold hammering and deep drawn plate and sheet.—R. P.

Improvement of Structural Steels by Alloying with Tungsten. L. Sas. (*Koh. Lapok*, 1957, **12**, Apr.-May, 163–169). The author reports Hungarian experiments on the heat-treatment and mechanical testing of Mn–W steel castings and forged bars of dia. 30–130 mm. The results of the experiments show clearly the increase in full hardening and a decreased tendency to overheating and temper brittleness by alloying amounts as low as 0·4% W. Based on these experiments the author suggests the introduction and use of 2% Mn and 0·4% W steels for replacing 2½% NiCr steels.—P. K.

A High-Strength Cast Steel. C. G. Mickelson and R. D. Engquist. (*Met. Prog.*, 1958, **73**, Mar., 97–98). A low-alloy Mn–Cr–Mo with B and rare earth additions which can be heat treated to tensile strengths above 220,000 p.s.i., has excellent ductility and impact properties and good wear-resistance is described. It is known as "Wearpact" and is used for dipper teeth for mining taconite ore and similar parts. The tooth design is shown.

The Comparability of Special Steels. (*Usine Nour.*, 1957, **13**, Oct. 24, 7). The High Authority of C.E.C.A. is studying the possibility of extending the classification already issued for structural steels to cover special steels, especially the high-speed steels. A note is here given reviewing recent publications giving specifications or descriptions of these steels in Germany, France, U.S.A., Italy, Belgium and Holland, and some discussion is added.

New Low-Alloy Structural Steels. I. S. Koslovskii. (*Vestnik Mashin.*, 1958, (2), 6–10). Chemical compositions of the new steels 18KhGT and 30KhGT are followed by their mechanical characteristics, details of thermal treatment and of the effect of small additions of boron.—L. H.

Low-Alloy High-Strength Steels. V. G. Paranjpe and S. Visvanathan. (*Tisco*, 1958, **5**, Jan., 1–9). The authors trace briefly the development of low-alloy high-strength steels and summarize the general requirements of structural steels. The mechanical properties and chemical compositions of high-strength steels are discussed and their weldability and corrosion resistance are considered. The authors conclude by indicating promising lines of development. (13 references).

[Review of Work] on Ball-bearing Steels. I. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 163–169). [In Japanese]. (27 references).—K. E. J.

A Fresh Look at Leaded Steels. W. Simon. (*Prod. Eng.*, 1958, **29**, Apr. 14, 72–73). Relatively low fatigue strength is set off against ease of machining. Properties are shown by tables and curves and comparison with sulphurized steels is made. Costs are briefly considered.

These Steels Have What Users Want. (*Steel*, 1958, **142**, Feb. 17, 126–129). Applications of 'TI,' a heavy duty steel developed by U.S. Steel Corp. are described. The steel is a quenched and tempered alloy with a yield strength about 3 times that of structural carbon steel; a typical composition is C, 0·15%; Mn, 0·92%; P, 0·014%; S, 0·020%; Si, 0·26%; Ni, 0·88%; Cr, 0·50%; Mo, 0·46%; V, 0·06%; Cu, 0·32%; B, 0·0031%. It may be used to advantage in 3 fields (1) where it allows lighter construction and cost savings (e.g. pressure vessels); (2) where it allows lighter construction and improved performance (e.g. shovel buckets); (3) where it gives improved performance (e.g. mine car bottoms).—D. L. C. P.

New Steel for Aircraft and Missiles. Interim Report on American Progress. (*Brit. Steel.*, 1958, **24**, Mar. 77–79). The properties of 'Armco PH15–7 Mo' are described. It is a new precipitation-hardening stainless steel of composition 0·09% max C; 1% max Mn; 0·04% max P; 0·04% max S; 1% max Si; 14–16% Cr; 6·5–7·75% Ni; 2–3% Mo; 0·75–1·5% Al. It has good corrosion resistance and good mechanical properties at room and elevated temperatures. The stress-strain behaviour shown by tests suggests its use where creep is a factor.—D. L. C. P.

Heat-Resisting Cast Steels and Their Structural Characteristics. K. Löbl and M. Vystyd. (*Slevarenství*, 1958, **6**, March, 72–76). The present state of such steels for elevated conditions in steam turbine installations throughout the world is reviewed, and their development in Czechoslovakia is seen to lag several years behind. Data sheets and creep curves of German and Russian steels are given, and a review of foreign literature sources, above all from Russia. Details are given of some comparable Czech ferrite–

pearlite and austenitic cast steels, but 12% Cr steels have not been produced.—M. T.

Note on Stainless Steels. A. Portevin. (*Ing. Mecc.*, 1957, **6**, Nov., 49–50). [In Italian]. This note is compiled from published information on the subject of stainless steels and gives a chronological description of the main developments which have taken place since the original work of pioneers like Osmond and Guillet. (11 references).—M. D. J. B.

American Stainless Steels. (*Mét. Constr. Mécan.*, 1958, **90**, Apr., 255–257). The article discusses the applicability of stainless steels to the atomic energy industry, with particular reference to American practice.

Stainless Steels and Heat-Resisting Steels, Standard Compositions. (*Aciers Fins Spéc.*, 1958, March, 102–113). The compositions, thermal treatment, and physical, mechanical and heat resisting properties are presented for stainless and heat-resisting steels in current use. A list of French producers is appended.

Diffusion of Cobalt into Iron–Cobalt Alloy. T. Hirone, N. Kunitomi, and M. Sakamoto. (*J. Phys. Soc. Japan*, 1958, **13**, Aug., 840–844). Diffusivity of ^{60}Co into the equiatomic alloy was measured by the lathe sectioning method over a range including the face centred to body centred cubic transition temperature and expressions for these structures are given. Activation energies are calculated and compared with theoretical values. It is concluded that a vacancy mechanism is responsible in both phases.

Electrolytic Heating. XI. Diffusion of Hydrogen into the Cathode. H. Mii, T. Sato, and S. Minowa. (*Rep. Gov. Ind. Res. Inst.*, 1958, **7**, Sept., 643–645). [In Japanese]. Tests with carbon steel at 850° C show that the H_2 diffusing into the cathode during electrolytic heating is less than that diffusing in from a salt bath, at high voltages; the amounts are not expected to produce hydrogen embrittlement.—E. E. J.

The Influence of Gases on the Quality of Pig-Iron and Cast Iron. (*Giesserei*, 1957, **44**, Dec. 5, 745–746). A brief article describing and comparing the effect of gases on the quality of pig iron and cast iron. This is affected by the composition, which in turn depends on the additions made and the manufacturing conditions. Experiments are described to determine the amount of various gases absorbed by graphite under various conditions. This article has been translated from a Russian article by V. Zednik and M. Sicha.—R. J. W.

Study on Graphitic Steel. III. Effect of Ti, V, and B on Graphitic Steel. T. Sato and S. Toya. (*Nippon Kinzoku*, 1956, **20**, June, 297–300). Results are reported for steels containing 1·3–1·5%C and 1·5%Si, to which are added 0·2–1·0%Ti, 0·2–1·0%V or 0·003–0·1%B. With increasing Ti and V, forgeability rises; the graphitizing effect of Ti is slightly negative and that of V strongly negative. With increase of B, the forgeability becomes poor and the amount of graphite decreases. The limits for alloying additions are determined as 1%Ti, 0·5%V, and zero B.

High-Strength Weldable Steels. I. Balsay. (*Kohászati Lapok*, 1958, **13**, Feb.-March, 72–80). In this first part of the paper the various types of high-strength weldable steels are discussed, and their chemical and mechanical characteristics given.—P. K.

The Iron and Steel Testing Station at Maizieres-les-Metz. (*J. Four. Elect.*, 1958, May-June, 101–103; *Echo Mines*, 1958, May, 288–292). An account of the opening on 22 Apr. and a general description of the station are given.

METALLOGRAPHY

The Metallographic View. H. E. Boyer. (*Steel Processing*, 1957, **43**, Apr., 205–206). **XXXIII. Metallography of Tool Steels. Water- and Oil-Hardening Types.** Tool steels are defined and typical analyses and structures are given after hardening and tempering. **XXXIV. Higher Alloy Types.** (May, 267–268). Compositions and structures are given of shock-resisting and hot work steels. The quenched-and-tempered states are illustrated. **XXXV. An Introduction to High Speed Steel.** (June, 324–325, 351). A brief review of types and compositions with microstructures of M2 steel after various treatments. **XXXVI. The High Speed Steels—Properties after Tempering.** (July, 330–331, 403). The mechanisms of hardening and tempering are outlined and structures of M–2 steel air-cooled from 2 200° F, 2 250° F, 2 300° F, and 2 350° F are shown, illustrating overheating. **XXXVII. High Speed Steels for Special Purposes.** (Aug., 437, 463, 464). Alloys with increased red hardness are reviewed. **XXXVIII. New Lower Alloy High Speed Steels.** (Sept., 504–505, 530). The structure and properties of MV1 steel are discussed and the microstructures are shown annealed, quenched and hardened and double tempered, all × 1 000. Impact properties are given. **XXXIX. The Martensitic Stainless Types.** (Oct., 568–569). Compositions are tabulated and microstructures shown after various heat treatments. **XL. Ferritic and Austenitic Stainless Types.** (Nov., 625, 646). Type 430 steel annealed, cold-worked type 302 and annealed type 321 are illustrated and their properties indicated. **XLI. The Effect of Heat Treatment on the Structure of A2 Cold Work Die Steel.** R. F. Harvey. (Dec., 696–697). AISI A2 steel has 1%C, 5·25%Cr, 1·15% Mo, 0·7%Mn, and 0·25%V. Quenched and tempered structures are shown and amount of retained austenite is tabulated. **XLII. Grain Size of High Speed Steel—The Effect of Reduction.** (1958, **44**, Jan., 33–34). Grain size reduction is related to heat treatment, bar size, and these, with compositions and structures for M10 and other types of Mo steel are discussed. **XLIII. The Effect of Hardening Temperature on the Microstructure of H13 Hot Work Die Steel.** (Feb., 82–83). Hardened and tempered structures are shown of Cr–Mo–V steel hardened from 1 850, 1 900, 1 950, 2 000, and 2 200° F. **XLIV. Importance of Multiple Tempering of High Speed Steels.** (Mar., 150–151). Effects on M6 steel are shown.

Metallographical Investigations of Archeological Remains. J. Piaskowski. (*Hutnik*, 1958, **25**, Jan.-Feb., 18–25). [In Polish]. The author puts forward a case for metallographic investigation of old metal objects. The investigation should be carried out in close co-operation with the archeologist and should include macroscopic observation, X-ray photography, hardness, and micro-hardness tests and chemical analysis.

The Practical Scope of the Use of Grids in Quantitative Metallographic Analysis. Z. Ministr. (*Hutn. Listy*, 1958, **13**, (7), 598–602). The utilization of rectangular grids in the determination of weight and volume fractions of phases in alloys from metallographic sections is considered. The most important formulae are derived, nomograms for use in practice are given, and sources of error are discussed.—P. F.

Metallographic Structure Analysis by Electron Micrography. I. Hrivňak. (*Hutn. Listy*, 1958, **13**, (6), 526–531). [In Slovak]. Methods of preparing collodion, polystyrene, and carbon replicas of metallographic samples are discussed in the light of the author's and other workers' recent publications.—P. F.

The Determination of Transformation Diagrams. J. Vaňa and D. Tlusta. (*Vyzkumne Prace z Oboru Železa a Oceli*, 1958, 119–137). Continuous-cooling transformation diagrams for 9 constructional steels were determined using dilatometry for low and interrupted end-quench for high cooling rates. The methods and apparatus are described.

An Instrument for Differential Thermal Analysis. A. Blažek and J. Halousek. (*Hutn. Listy*, 1958, **13**, (6), 505–509). The principles of DTA are explained, and details of the construction of a simple self-registering analyser designed by the authors are given. The analyser uses a photocell amplifier, the photocell being activated by light from a mirror which is part of the suspension of a sensitive galvanometer series connected with the Pt–Pt/Rh thermocouple.—P. F.

Abnormal Structure in Alloys of Eutectoid and Eutectic Type. V. (*Nippon Kinzoku*, 1956, **20**, Aug., 457–460). The appearance of abnormal structures in hyperalloys is correlated with critical ratios on the eutectic phase diagram. This is confirmed by observations on Cu–Si alloys.—K. E. J.

Diamond Abrasives in Metallographic Polishing. L. E. Samuels. (*BSCRAJ.* reprint, 1957, Dec., pp. 4). Superior polish at no greater cost can be obtained.

The Differentiation of Phases in Metallographic Etching. I. Electrolytic Etching at Controlled Potential. M. Pražak, V. Cihal, and M. Holinka. (*Chem. Listy*, 1958, **52**, (9), 1 693–1 698). Ferritic and austenitic 18%Cr–9%Ni stabilized with Ti were examined.

A Study on the Methods for Revealing the Austenite Grain Size in Steel. A. Adachi, K. Mizukawa, and N. Hiraoka. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1958, **8**, Mar., 131–139). Six published methods were examined. A new method depending upon lead diffusion in which a surface protected with tin was stripped and placed in molten lead for 1 h after which the lead was removed and the structure examined with dithizone as reagent for diffused Pb is described.

Investigation of Phase Composition of Iron–Vanadium and Iron–Chromium Alloys. M. I. Zakharova, I. A. Ignatova, L. A. Semenova, and N. A. Khatanova. (*Doklady A.N.*, 1958, **119**, (3), 498–500). Fe–V and Fe–Cr alloys were studied by means of X-ray powder photographs. Fe–V alloys at 1 300° (and quenching) with V from 28·5 to 74% are made of two phases: α-phase (cubic, body-centric), and β-phase (cubic, face-centric), hard modification, with 4·12Å for the alloy with 43%V. Other results are obtained at 800° and 600° C. In the case of Fe–Cr alloys at 1 400° only the β-phase is present but its quantity is reduced with the lowering of the temperature of quenching.—S. I. T.

Investigations of an Ordered Atomic State in Iron–Nickel–(Platinum) Alloys with Low Thermal Expansion. A. Kussmann and K. Jessen. (*Arch. Eisenh.*, 1958, **29**, Sept., 585–594). Experiments were carried out to account for variations in properties (particularly the coefficient of thermal expansion and displacement of the magnetic transformation point) in heat-treated Fe–Ni alloys containing 30–40%Ni on tempering at 500° C, by making comparative experiments on Fe–Pt Invar alloys with 24–33%Pt, and on ternary alloys between these regions. A critical examination of the results led to the conclusion that an ordered atom state Fe_3Ni occurs in the γ-phase of Fe-rich Fe–Ni alloys on heat treatment, and accounts for the variation in properties.

Distribution of Alloying Elements in Austenitic Chromium–Tungsten Steels and Alloys with Varying Nickel Contents. N. F. Lashko and E. Ya. Rodina. (*Fiz. Met.*, 1957, **5**, (2), 261–267). The results are given of phase analyses of Cr austenitic steels and alloys containing varying concentrations of Ni (20–60%), W, V, and Nb.

Thermodynamic Studies on the Formation of Molten Silicon Alloys Using Galvanic Cells. III. The System Iron–Silicon. K. Sano and K. Okajima. (*Nippon Kinzoku*, 1956, **20**, Sept., 512–514). Activity results for molten Fe–Si alloys show both positive and negative deviations from Raoult's law. A discrepancy with Chipman's results at $N_{Si} > 0·55$ is noted.—K. E. J.

The Uranium–Iron Equilibrium Diagram for Low Iron Concentrations. J. Bellot, A. Blanchon, R. Chazot, P. Dosière, J.-M. Henry, and M. Colas. (*Compt. Rend.*, 1958, **246**, May 28, 3 063–3 065). This investigation covers the range of alloys containing less than 0·3% iron, particular attention being paid to the solubility curve of iron in β-uranium.—L. D. B.

CORROSION

A Classification Scheme for Corrosion Topics. D. M. Brasher. (*Corros. Prev.*, 1958, **5**, Feb., 39–42). A classification scheme, intended as a basis for the compilation of a complete corrosion bibliography and for recording and indexing technical enquiries, has been developed. The author describes briefly the classification tables and index, and gives examples of their use and application.—L. E. W.

The Corrosion of Pipes in the Earth and Their Protection. L. Scuri. (*Calore*, 1958, **24**,

July, 317–323). [In Italian]. The author considers electrolytic and galvanic corrosion of pipes in the ground. Means of preventing corrosion by cathodic protection and drainage are discussed. (9 references).—M. D. J. B.

The Mechanism of Subterranean Corrosion of Iron. T. Marković. (*Zaštita Mat.*, 1958, **6**, (4), 147–151). [In Serbocroat]. The physical principles underlying the corrosion of iron submerged in soil are considered. The amount of water in the soil and the water/air ratio are shown to be most important parameters in relation to the corrosion rate.—P. F.

Corrosion of Subterranean Water Ducts which are Cathodically Polarized. P. Kirkov. (*Zaštita Mat.*, 1958, **6**, (2), 55–60). [In Serbocroat]. A report is given of studies of the corrosion of water ducts in and around Skoplje. The corrosion rate is conditioned by potential gradients along the tubes resulting from varying physical and chemical properties of the soil containing them. Cathodic protection can be used successfully to minimize the corrosion.—P. F.

Studies on Corrosion at Power Generation Stations Using Acid River Water. XVI. Effect of Heat-Treatment on Corrosion Resistivity and on the Corrosion of Welded Parts. Y. Sawada. (*Nippon Kinzoku*, 1956, **20**, June, 308–311). When 13%Cr steels, after rapid cooling from the γ-phase, are tempered at 500–600° C, the corrosion rate increases, probably because of pptn of chromium carbides. With tempering above 700° C it is reduced, probably because of uniform distribution of Cr. Welded parts are usually deeply corroded, but this can be prevented by tempering above 700° C after welding. With 1%Ti added to the steel, freshly welded parts are not corroded. **XVI. Field and Service Tests of High Chromium Steels.** S. Shimodaira and Y. Sawada. (Aug., 432–435). Studies were made on hydraulic turbines and other plant. Steels containing 13%Cr, 0·1%C, and 1–2% Mo, Cu or Ti remained passive to acid river water for 2 years. Plain 13%Cr–0·1%C steel is corroded unless adequately heat-treated.

Wear Due to Water Containing Sand in Hydraulic Plants. W. A. Stauffer. (*Schweiz. Arch. Wiss. Techn.*, 1958, **24**, July, 218–230). Several examples of wear in turbine parts due to sand erosion are given, with a description of their characteristic features. An account is then given of two large series of erosion tests, with fully tabulated results; the tests are on rolled and forged steel, and on cast steel with a wide variety of compositions.

Corrosion Stability of Metals for Hydraulic-Turbine Parts. M. G. Timerbulatov. (*Metallov. Obrabotka Met.*, 1957, (10), 12–18). The results of corrosion tests on the following materials, used for hydraulic turbine construction, are presented and discussed: 18DGSL steel (0·17–0·22%C, 0·60–0·87%Si, 1·08–1·22% Mn, 0·023–0·039%S, 0·015–0·020%P, 1·28–1·62%Cu) after various heat treatments; the same with addition of 0·97 or 1·60%Ni or 0·092 or 0·13%P; samples taken from various points of a large turbine blade casting of 20GSL steel (0·19%C, 0·72%Si, 1·10%Mn, 0·018%S, 0·025%P, 0·18%Cr, 0·13%Ni, 0·08%Cu), stainless 20Kh13NL steel laboratory and industrial castings (0·18–0·23%C, 0·30–0·46%Si, 0·34–0·53%Mn, 0·018–0·024%S, 0·015–0·020%P, 12·33–12·60%Cr, 0·64–1·20%Ni, 0–0·15%Cu); high-strength spheroidal-graphite iron and welded joints in it. The corrosion of the latter in flowing water was 40–50% greater than that of the 20GSL and 18DGSL steels; heat treatment conditions for the latter are recommended. The phosphorus and nickel additions had little effect on the corrosion rate.—S. K.

Pitting of Shipbuilding Steel in Crude-Oil Tankers. G. Becker. (*Stahl Eisen*, 1958, **78**, Sept. 18, 1343–1345). A review of two papers published in *Schiff u. Hafen* in 1956 and 1957 on the mechanism of corrosion pitting in oil tankers. Corrosion takes place by an electrochemical reaction in almost neutral electrolytes of high conductivity. The current required for the dissolution of the iron is generated by local cells involving oxygen depolarization. Cleaning the tanks by hot sea water contributes much to corrosive attack. It was found that corrosion-resistance shows a definite minimum at a certain level of the alloying elements of the steel. It is concluded that the pitting is a combined effect of cavitation caused by the hot sea water jets and of corrosion.—T. G.

Corrosion Study. XV. Mechanism of the Formation of Corrosion Products on Steel and Zinc in a Moist Atmosphere with a Low Content of HCl Vapour. K. Bartoň, E. Beránek, and S. Bartoňová. (*Coll. Czechoslovak Chem. Comm.*, 1958, **23**, July, 1169–1173). The kinetics of the atmospheric corrosion of steel and zinc and the composition of the corrosion products formed in moist atmospheres with low HCl vapour contents were investigated. It was found that corrosion began only after the destruction of the primary oxide layer. **XVI. The Influence of the Penetration of Water Vapour through Oil Films on the Corrosion of Steel Protected by Oil Layers.** R. Bartoníček. (1174–1180). Experiments are described to determine the rate of penetration of water vapour through protective mineral oil coatings, and to investigate the effect of the addition of inhibitors.—L. D. B.

Corrosion Studies, VIII. Temperature Dependence of the Potential of Certain Metals. K. Smrček, I. Sekerka, and V. Seifert. (*Coll. Czechoslovak Chem. Comm.*, 1956, **21**, (6), 1569–1574). The effect of the corrosion products on potential is also determined. The curve for iron is included. **IX. Corrosion of Iron and Duralumin as Related to the pH of the Solution.** K. Smrček. (1575–1583).

Adsorption of Sulphur on Iron from Acid Solutions of Hydrogen Sulphide. Z. A. Iofa. (*Doklady A.N.*, 1958, **119**, (5), 971–974). Tracer isotope ^{35}S was used in these experiments on iron plates in a solution of $H_2SO_4 + Na_2S$. The values of adsorption for various concentrations and times are given. The addition of an inhibitor, tetrabutylammonium ion, did not influence adsorption. Numerous details are given and discussed.

Barrier Materials and Dehydrating Agents. F. M. de Balasy. (*Rev. Gén. Méc.*, 1958, **42**, Apr., 207–209). A description of the technique of packaging machine tools and other parts combined with the use of dehydrating agents for protection against corrosion during transport and storage.

The Control of Corrosion in Industry. J. Strebelle and M. Stassin. (*Métaux–Corrosion–Indust.*, 1958, **33**, Mar., 115–124). A review of work on corrosion carried out in Belgium by CEBELCOR, is presented. The case history of a number of plant failures due to corrosion are discussed.—B. G. B.

Protection against Corrosion of Steel Members Used in Building. P. Blancheteau. (*Corros. et Anticorros.*, 1958, **6**, June, 191–202). After giving an account of the use of steel in building, the author describes the anticorrosive measures used to protect the steel, i.e. paint, varnish, metallic coatings, and vitreous enamels.

Protective Potentials of Metals. V. V. Gerasimov. (*Isvest. Akad. Nauk, Otdel. Khim.*, 1957, (3), 263–269). A new method is described of calculating the protective potential of metals; the method was tested on Cu, Zn, Cd, Mg, Pb, Fe, and cast iron in a 1·5% solution of NaCl.

Investigations on the Cathodic Protection of Ships' Hulls. R. Juchniewicz. (*Werkstoffe Korrosion*, 1958, **9**, June, 360–368). The results are given of a survey carried out by the Anstalt für Meerwasserkorrosion of the Technische Hochschule, Gdansk. Details are reported of potential measurements of corroded ship's hulls and of a floating ship's hull protected by a special paint. Corrosion tests were carried out on a model hull and on tanker ballast tanks. (36 refs.).—L. D. B.

Resistance to Corrosion of Stainless Steels. Intergranular Corrosion. (*Acciaio Inossid.*, 1958, **25**, Jan.-April, 5–16; May-June, 61–72). [In Italian]. The paper discusses the 'sensitivity' of austenitic stainless steels and shows that intergranular corrosion is not so much a function of the corrosive agent in contact with the stainless steel as of the structure of the steel itself. Methods of determining intergranular sensitivity are described and results of tests are given. Processes which can affect sensitivity are discussed and means of counteracting it are reviewed.—M. D. J. B.

Corrosion Protection of Galvanized Sheet. L. Krošar, O. Jagrović, and F. Podbrežnik. (*Zaštita Mat.*, 1958, **6**, (3), 129–133). [In Serbocroat]. An increase in corrosion resistance is attainable by the use of additional coating agents. The effectiveness of several such coatings was tested in accelerated corrosion tests. A chlorinated rubber type coating was found to be most effective.—P. F.

The Protective Action of Chromium Against the Corrosion of Fe–Cr Alloys by Sulphur Vapours. A. K. Semenova and P. V. Gel'b. (*Fiz. Met.*, 1957, **5**, (2), 378–379). Experiments are described in which Fe–Cr alloys of varying compositions were exposed to the action of sulphur vapour, in order to verify the hypothesis that a protective inner layer of the spinel $FeCr_2S_4$ was formed.

Special Steels Resistant to Stress Corrosion by Hydrogen Sulphide. P. Bastien, H. Véron, and C. Roques. (*Rev. Mét.*, 1958, **55**, Apr., 301–317). The principles of the embrittlement of α-steels by atomic hydrogen are discussed and the properties of Cr–Mo–V steels with particular reference to hydrogen embrittlement are described. Tests on hydrogen embrittlement and stress corrosion have shown the great influence of the mechanical properties of the steel and of cold work and composition.

Anti-Corrosion Treatment of Galvanized Parts. N. A. Solovev and A. A. Gorbenko. (*Metall. Obrabatka Met.*, 1957, (2), 54–58). Research into the treatment of galvanized coatings in a sol. of CrO_3, H_2SO_4, and HCl. This process was introduced at the Yaroslav motor car plant in 1947.—R. S.

ANALYSIS

Studies on the Rapid Analysis of Iron and Steel Using a Photoelectric Photometer. VI. Rapid Photometric Determination of Small Amounts of Arsenic in Iron, Steel, and Iron Ore. O. Kammori. (*Nippon Kinzoku*, 1956, **20**, Aug., 446–448). A method is described whereby 0·005–0·07% of As can be determined in 25–35 min with a reproducibility of ± 0·001%.—K. E. J.

Polarographic Determination of Iron, Using Sucrose as a Complexing Agent. O. Manoušek. (*Collection of Czechoslovak Chemical Communications*, 1958, **23**, Mar., 394–401). [In German]. Iron can be determined polarographically in alkaline sucrose solution. To eliminate interference due to Mn, Ca, and Mg the disodium salt of EDTA was used.—L. D. B.

Mutual Determination of Iron and Tropolone. Y. Oka and S. Matsuo. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1958, **10A**, Aug., 299–305). Colorimetric methods for iron in excess tropolone (brown) and tropolone in excess iron (green) are given.

Complexometric Titration (Chelatometry). XI. 1 : 2-Diamino*cyclo*hexane-*NNN'N'*-tetraacetic Acid as a Volumetric Reagent. Stepwise Determination of Iron and Manganese (Magnesium, Calcium); Determination of Copper in Presence of Iron, Nickel Cobalt, and Manganese. R. Přibil. (*Coll. Czechoslovak. Chem. Comm.*, 1955, **20**, (1), 162–169). [In German]. **XVI. Determination of Bismuth, Nickel, and Cobalt with Pyrogallol Red.** V. Suk, M. Malat, and A. Jeníčkova. (1956, **21**, (2), 418–422). **XVII. A Contribution to the Determination of Copper, Iron, Aluminium, and Titanium.** Z. Šir and R. Přibil. (1956, **21**, (4), 866–872). [In German]. The uses of Eriochrome Black T and Pyrocatechol Violet are described. **XVIII. The Determination of Nickel and Copper in Cobalt and its Salts.** F. Vydra and R. Přibil. ((5), 1146–1149). Complexone and Chenta-reagent (1 : 2-diamino*cyclo*hexanetetra-acetic acid) are used.

The Direct Determination of Combined Carbon in Gray Pig Iron and Cast Iron. H. Krapp and K.-H. Tytko. (*Giesserei*, 1958, **45**, Oct. 9, 639–642). Combined carbon is determined directly by burning the hydrocarbons evolved on heating with H_2SO_4 in a stream of O_2 on a glowing Pt spiral, and determining the resulting CO_2 volumetrically. The error is less than that obtained by difference using routine methods.

BOOK NOTICES

The High-Sensitivity Determination of Sulphur and the Simultaneous Determination of Carbon and Sulphur with a Recording Conductivity Apparatus. W. Koch, S. Eckhard, and H. Malissa. (**Arch. Eisenh.*, 1958, **29**, Sept., 543–546). An apparatus is described for the simultaneous and accurate determination of C and S in iron and steel samples by combustion in O_2, followed by measurement of conductivity changes in suitable absorbants. The method can be adapted for macro or micro determinations of S.

The Determination of Trace Amounts of Cobalt in Iron and Steel and Some Associated Materials. The BISRA Methods of Analysis Committee. (*JISI*, 1959, **191**, Mar., 236–240). [This issue].

The Spectrographic Analysis of Metallic Chromium for Silicon, Aluminium, and Iron. Ya. M. Kalinskii. (*Zavods. Lab.*, 1958, **24**, (6), 755). The details of the spectrograph and microphotometer used, the conditions of excitation, and the line pairs employed in the spectrographic analysis of Cr for Si, Al, and Fe are described.

Spectrographic Analysis of Blast Furnace Slags. R. I. Petukhova. (*Zavods. Lab.*, 1958, (4), 463). In the laboratories of the Bielo Russian Metallurgical Combine, spectrographic analysis of blast furnace slags for Ca oxides and Si was studied in 1947. The method has since been improved. The lines Ca 5270,2 Å–Cu 5292,52 Å and Si 6346 Å–Zn 6262 Å are now used. The full procedure is explained.

Use of Radioactive Isotopes in Mining and in the Iron and Steel Industry. L. G. Erwall. (*Jernkont. Ann.*, 1958, **142**, (7), 369–397, discussion 397–400). Studies on mineral sorting, flotation, corrosion, refractory wear in blast-furnaces, gas and materials transport, amount and reactions of slag, phase boundary distribution and inclusions in continuous casting, analytical studies, thickness measurement and die wear in wire drawing are reported after an account of principles and the apparatus used. The use of non-radioactive isotopes is also referred to. (34 refs.).

The Rapid Investigation of Ores and Similar Materials. A. Neuberger, E. Schöffmann, and K. Herkenhoff. (**Arch. Eisenh.*, 1958, **29**, Sept., 547–552). Rapid methods are described for the analysis of ores and similar materials by first fusing with borax, and then determining from a single weighing Fe, Mn, SiO_2, P, Ca, Mg, Al and Ti oxides, and Cu, Cr and Pb, using photometric and flame-photometric methods.

Analysis of Silica in Silicates. I. A. Voinovitch. (*Chim. Anal.*, 1958, **40**, Sept., 332–339). A comparison of gravimetric, volumetric, spectrophotocolorimetric, and emission spectrographic methods is given and recommendations are made. (23 refs.).

Recent Progress in the Complexometric Determination of Calcium and Magnesium in Slags. V. Kuhn. (*Chim. Anal.*, 1958, **40**, Sept., 340–347).

INDUSTRIAL USES AND APPLICATIONS

On Austenitic Stainless Steel Tubes for High Temperature and High Pressure Boilers. T. Ikeshima, J. Omori, T. Okamoto, E. Miyoshi, S. Terai, and H. Maruoka. (*Sumit. Met.*, 1958, **10**, Jan., 9–30). Tubes of types 321 and 347 stainless steels for superheaters in boilers are examined. Physical and creep-rupture properties are comparable with data specified by the A.S.T.M. Impact values fall after heating for 1 000 h at 600°, 650°, and 700° C, but the minimum of 5 kg-m/cm² is acceptable. Sigma phase is found after 1 000 h heat-treatment. Oxidation is negligible below 700° C. Inert-gas arc welding is preferable to arc welding; care is needed, and three types of electrode are recommended. Cold bending of the tubes is possible.—K. E. J.

Development of a Special Steel for the Electrical Engineering Industry. P. Jehlička and R. Vokač. (*Vyzkumne Prace z Oboru Železa a Oceli*, 1958, 189–196). A steel for vacuum use is described.

A New Pipe Line at Lacq, Made by Lorraine-Escaut. (*Technique Moderne*, 1958, June, 274). A special steel tubing is discussed which is suitable for corrosive gases at high temperatures and pressures, particularly H_2S.—R. P.

Improvement of the Quality of Steels (Czechoslovak Standard ČSN 12040) for Cold-Headed Screws and Bolts. D. Tlusta. (*Vyzkumne Prace z Oboru Železa a Oceli*, 1958, 173–188). The effect of O_2 blowing in the O.H. was studied. It proved to give lower P, S, and gas content and better cold-headability. Surface quality was related to rolling method and to effects on cold-heading.

Quality Steel for Razor Blade Manufacture. D. Tlusta and J. Votruba. (*Vyzkumne Prace z Oboru Železa a Oceli*, 1958, 63–82). Comparison with Swedish steel is made. The importance of uniform carbon content in the strip is shown also of correct annealing, and a temperature above the A_1-point is recommended.

Studies on the Materials for Gas Turbine Rotors. T. Hasegawa and O. Ochiai. (*Sumi. Met.*, 1958, **10**, Apr., 68–80). Studies of effects of heat-treatment on creep and other properties of Timken 16–25–6 are reported. Structures are illustrated. Test results are tabulated in English.

Springs for Alarm Clocks. O. Modraček and K. Staňka. (*Vyzkumne Prace z Oboru Železa a Oceli*, 1958, 139–147).

HISTORICAL

The Manufacture of Steel Blades in Ancient Times. C. Panseri. (*Assoc. Ital. Metallurgia, Milan*, 1957, pp. 80). [In Italian]. The booklet is a collection of papers describing the metallurgical properties and techniques of manufacture of war swords dating from the 7th century B.C. to the Middle Ages. Much of historic interest is brought to light. Numerous illustrations are given and comprehensive bibliographies are included which will be of considerable value to all interested in the history of metals.—M. D. J. B.

Metallurgical Research on a XIIth Century Sword. C. Panseri. (*Assoc. Ital. Metallurgia, Milan*, July, 1954, pp. 35). The monograph describes detailed metallurgical studies carried out on a XIIth century war sword found in 1948 at Legnago in the Adige Valley. The article is of considerable historical interest and shows how modern metallurgical techniques can be brought to the service of history. Numerous illustrations are given.—M. D. J. B.

Early Days of Hydraulic Pumps in Italy. B. Boni. (*Fond. Ital.*, 1958, **7**, May, 161–168; *Met. Ital.*, 1958, **50**, June, 167–174). [In Italian]. The adoption of hydraulic pumps in place of large leather bellows which were costly to build and maintain, contributed to technical progress in the early days of the iron and steel industry. The cheapness and simplicity of these pumps resulted in their continued use for three centuries up to the mid-19th century. The hydraulic pump was used almost universally in Europe and even found its way into the U.S.A. The author shows how these pumps affected developments in smelting techniques.—M. D. J. B.

Jung-Stillung and Iron. W. Güthling. (*Stahl Eisen*, 1958, **78**, Oct. 2, 1 395–1 399). A biography is presented of Johann Heinrich Jung, called Jung-Stilling, born in 1740 in the Sieg district of Germany. His reports on Western German iron smelting and manufacturing practice give a true picture of the industry of his time.—T. G.

Practical Realization of the Acid Bessemer Process in Sweden. E. Öhmann. (*Jernkonts. Ann.*, 1958, **142**, (6), 269–270). An historical note on early developments.

Fifty Years of Electric Steel Production in Czechoslovakia. R. Stefec. (*Hutn. Listy*, 1958, **13**, (5), 389–397). The development of electric steel production in Czechoslovakia since the installation of the first Kjellin type induction furnace in the Poldi Steelworks in Kladno in 1908 is discussed in detail.—P. F.

ECONOMICS AND STATISTICS

Chromium. W. McInnes and H. V. Heidrich. (*U.S. Bur. Mines Min. Yearbook*, 1955, **1**, 317–332). **Cobalt.** H. W. Davis and C. R. Buck. (359–371). **Columbium and Tantalum.** K. B. Higbie. (373–385). **Ferroalloys.** P. H. Royster and H. V. Heidrich. (451–462). Ferromanganese, ferrosilicon, high-silicon iron, ferrochromium, ferrotitanium, ferrophosphorus, ferrovanadium, ferroniobium, ferroboron and ferrotungsten are reviewed. **Manganese.** G. L. DeHuff and T. Fratta. (747–770). **Molybdenum.** W. McInnis and M. J. Burke. (823–832). **Nickel.** H. W. Davis. (841–857). **Titanium.** J. A. Miller. (1171–1193). **Tungsten.** R. W. Holliday and M. J. Burke. (1195–1211). **Vanadium.** H. W. Davis and P. M. Busch. (1243–1252). In all cases statistics of world output, import and export and utilization are given.

The Effect of Transport on the Location of Iron and Steel Works. J. Pinot. (*Rev. Ind. Min.*, 1958, **40**, Aug., 603–614). Location on coal fields or sources of iron ore, canals and waterways, Lorraine and the Schuman plan are all discussed.

MISCELLANEOUS

Electrolytic Extraction of Cobalt from Cobalt-containing Residues from Zinc Electrometallurgy. M. G. Scacciati. (*J. Four. Elect.*, 1958, May–June, 97; from *Met. Ital.*, 1957, **49**, Oct., 713–720). The process carried out at the Sta. Montevecchio works at Porto-Marghera is described.

Getting the Most from a Drying System. J. E. Greever. (*Met. Prog.*, 1958, **74**, July, 8385). The drying of commercially available gases is described using N_2 as an example. Dew points of — 90° to — 95° F are readily obtainable.—T. G.

Fault-Finding in Electronic Equipment. H. C. A. Dale. (*Ergonomics*, 1958, **1**, Aug., 356–385). A study has been made on training for fault location. It is found that most operators do not search efficiently and that knowledge of electronic theory is not sufficient. A positive correlation of effective searching procedure with intelligence was established. Trials on untrained operators on simulated systems were carried out and evaluated. The optimum number of checks was 4·4 and the average number of moves was 6·4 in one case.

Resistivity and Density of Polycrystalline Yttrium Iron Garnet. L. G. Van Uitert and F. W. Swanekamp. (*J. Appl. Phys.*, 1957, **28**, Dec., 1513–1514).

On Breaks for Meals for Workers in an Iron and Steel Works. M. Nakamura. (*J. Labour Hygiene in Iron and Steel Industry*, 1957, **6**, Aug., 26–30, 31–37). [In Japanese]. A study of 19 052 workers was made and the habits of day and shift workers were analysed.

Multiphase Screening Examination of Industrial Workers. M. Ichinose. (*J. Labour Hygiene in Iron and Steel Industry*, 1957, **6**, Aug., 43–49). Medical findings on workers aged 40 and over are analysed.

Labour Hygiene Investigation for Blast Furnace Workers. S. Shinjo. (*J. Labour Hygiene in Iron and Steel Industry*, 1957, **6**, Aug., 14–18). [In Japanese]. The water metabolism and blood composition of 12 workers on a 1000-t blast furnace were studied.

On the Serum Protein Pattern of Open-Hearth Steel Melters. S. Shinjo. (*J. Labour Hygiene in Iron and Steel Industry*, 1957, **6**, Aug., 38–42). Effects suggesting changes due to continual exposure to heat were noted.

1958, Vol. 188.

p. 285, Col. 1, line 35.
for "J. Bardin" read "I. Bardin."
p. 292, Col. 1, line 38.
for "Chakravarty" read "Chakravarty."
p. 300, Col. 2, line 33.
The "I" is the author's initial.
p. 394, Col. 1, line 13.
For "Selmeizi" read "Selmaczi".
p. 419, Col. 1, line 20.
For "Savvina" read "Savrina."

British Locomotive KIRKSTALL

BOOK NOTICES

SEDLACZEK, HERBERT. "*Walzwerke*," Mitarbeit von Priv. Doz. Dr.-Ing., F. Fischer und Dipl.-Ing. M. Buch, Sammlung Goschen Band 580/580a. 6 × 4 in., pp. 224 [+ 3]. Illustrated. Berlin, 1958: Walter de Gruyter & Co. (Price DM. 4.80).

This is quite a remarkable little book. Printed in a pocket size format and a mere 200 pages long, it nevertheless covers almost all topics relating to rolling in an elementary and most readable manner, including fundamentals of rolling mill design and layout, principles of pass design, main types of mill for the rolling of sections, tubes, and strip, and even for the manufacture of rings and furnaces. Naturally, to achieve this, the author had to treat many matters rather superficially; even so, he has, on the whole, managed to include all salient points of practical interest. The only criticisms relate to the first two chapters on fundamentals, the treatment of which is too cursory to be of any use to the reader, and to the bibliography which has obviously not been well checked and contains many reference topics other than rolling, and being arranged alphabetically by authors is hardly designed to help the reader in following up particular topics. The text is illustrated by over 150 sketches, drawings, and photographs, most of which are readily comprehended despite their small size.
J. G. WISTREICH.

SINNOTT, M. J. "*The Solid State for Engineers*," 9 × 6 in., pp. xi + 522. Illustrated. New York, London, 1958: John Wiley & Sons, Inc., Chapman & Hall Ltd. (Price £5).

Nowadays there is a widespread feeling that engineers should be asquainted not only with the macroscopic properties and behaviour of materials, but also with the underlying microscopic and atomic explanations provided by solid-state physics. This, it is hoped, will enable engineers to use greater insight in selecting materials for specific purposes and to make the best use of their potentialities by understanding their inherent limitations. The "Solid State for Engineers" sets out to fulfill this need. Modern ideas on mechanical, thermal, electric, magnetic, and optical properties are all discussed, following introductory chapters on atomic structures, crystal structures, thermodynamics, rate processes, and the different types of solid arising from different types of atomic and molecular bonding. The range of subjects is in fact so wide that even though the author takes great care, a student new to the field will have great difficulty in following some of the arguments, and appreciating their real significance. A longer treatment of fewer topics would probably have been better.

However, the main weakness of this book lies in its academic, and largely theoretical treatment. The subject matter is not brought to life and substantiated by sufficient reference to the most significant experimental information and applications. The physics is not related clearly enough to engineering problems, thereby giving point and purpose to the former, and clarification to the latter. A similar book, which in the reviewer's opinion, succeeds where this book valiantly fails is "The Science of Engineering Materials" (Ed. J. E. Goldman, 1957, same publishers—reviewed *J.I.S.I.*, June, 1958, p. 194). The writing of this type of book is a difficult task for one man. It is perhaps significant that the more successful book was compiled from articles by scientists each active and expert in his own field, but with a clearly defined over-all objective in view.—ALLAN GREEN.

NEW PUBLICATIONS

AMERICAN SOCIETY FOR TESTING MATERIALS. "*ASTM Manual on Quality Control of Materials*." STP No. 15-C. 9 × 6 in., pp. xii + 134. Illustrated. Philadelphia, 1958: The Society. (Price, Members, $2.00, Non-Members, $2.50).

BAUER, E. "*Elektronenbeugung, Theorie, Praxis und industrielle Anwendungen*." 8½ × 5½ in., pp. 233. Illustrated. München, 1958: Verlag Moderne Industrie. (Price DM. 32.00).

BENNETT, H. E. "*Noble Metal Thermocouples*." 2nd edition. 9½ × 6¾ in., pp. 41. Illustrated. London, 1958: Johnson, Matthey & Co. Ltd.

AMERICAN SOCIETY FOR TESTING MATERIALS. "1957 *References on Fatigue*." STP. No. 9-I. 11 × 8½ in., pp. 64. Philadelphia, 1958: The Society. (Price $3.00).

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Specifications and Tests for Electrodeposited Metallic Coatings*. 9 × 6 in., pp. vii + 116. Illustrated. Philadelphia, 1958: The Society. (Price, Members $1.80, Non-Members $2.25).

AMERICAN SOCIETY FOR TESTING MATERIALS. "1957 *Supplement to the Bibliography and Abstracts on Electrical Contacts*." STP. No. 56-L. 9 × 6 in., pp. 49. Philadelphia, 1958: The Society. (Price, Members $1.40, Non-members $1.75).

AMERICAN SOCIETY FOR TESTING MATERIALS. "*ASTM Standards on Gaseous Fuels*." 9 × 6 in., pp. vi + 198. Illustrated. Philadelphia, 1958: The Society. (Price Members $2.40, Non-Members $3.00.)

ATTIA, M. I. "*Topography, Geology and Iron-Ore Deposits of the District East of Aswan*." 11 × 7¾ in., pp. xii + 262 [+ 38 Plates & map]. Illustrated. Cairo, 1955: Les Editions Universitaires d'Egypte. (Price P.T. 225).

BURMESTER, HANS-JÖRN. "*Hartmetallwerkzeuge für die Feinbearbeitung*." (Schriftenreihe Feinbearbeitung H. 29). 8vo, pp. 55. Illustrated. Stuttgart, 1958: Deva-Fachverlag. (Price D.M. 4.60).

"*Business and Specialised Publications of Great Britain*." 8¼ × 6 in., pp. 111. London, 1958: Periodical Proprietors Association Ltd.

"25*ème Congrès International de Fonderie*." Bruxelles, 1958. 10½ × 8½ in., pp. 735. Illustrated. Brussels, 1958: Association Technique de Fonderie de Belgique.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH. "*Crushing and Grinding. A Bibliography*" 9¾ × 6 in, pp. ix + 425. Illustrated. London, 1958: H.M.S.O. (Price 35*s*.).

INTERNATIONAL UNION OF THEORETICAL AND APPLIED MECHANICS. "*Verformung und Fliessen des Festkörpers*." (Kolloquium Madrid 26 bis 30 September, 1955). 8vo, pp. xii + 324. Illustrated. Berlin, 1956: Springer-Verlag. (Price DM. 37.50).

JONES, N. H. "*Factories Acts* 1937 & 1948. *A Concise Summary Applicable to Iron Steel Works*." 6 × 4 in., pp. 72. Sheffield, 1958: The United Steel Companies Ltd.

KOCH, WALTER UND HEINZ SUNDERMANN. "*Elektrochemische Grundlagen der Isolierung von Gefügebestandteilen in Metallischen Werkstoffen*." (Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nord-hein-Westfalen. Nr. 599). 4to, pp. 50. Illustrated. Köln und Opladen, 1958: Westdeutscher-Verlag. (Price DM. 17.60).

LANGE, KURT. "*Gesenkschmieden von Stahl*." 8vo, pp. xii + 379. Illustrated. Berlin, 1958: Springer-Verlag. Price DM. 54.00).

"*Lindsay's International Register of Wire, Rod and Strip*." 1957–1958 ed. 9½ × 6 in., pp. 248. Illustrated. Wolverhampton, 1958: Lindsay's Wire Publications. (Price 25*s*.)

MAYER, KARL ERNST. "*Wege zur Automatischen Überwächung des Thomasverfahrens*." 4to, pp. 47. Illustrated, Clausthal, 1958: Bergakademie, (Dr.-Ing.-Diss.).

MEINECKE, EWALD. "*Möglichkeiten einer Aufbereitung der Ilseder Eisenerze und ihr Einfluss auf den Hochofenmöller*." 4to, pp. 59. Illustrated. Clausthal, 1958: Bergakademie. (Dr.-Ing.-Diss.)

MEYRICK, N. L. (compiler). "*Fifteen Years of Semi-Conducting Materials and Transistors. A Bibliography*." 11 × 8½ in., pp. 75. Newmarket, 1958: Newmarket Transistor Co. Ltd.

MINISTRY OF POWER. "*The Efficient Use of Fuel*." 2nd edition. 9½ × 5¾ in., pp. vii + 888. Illustrated. London, 1958: H.M.S.O. (Price 25*s*.).

MÜLLER, HARALD (Editor). "*Jahrbuch der Electrowärme*." Mit Empfehlung des Deutschen Komitees für Elektrowärme. 8vo, pp. 437. Illustrated. Essen, 1957: Vulkan-Verlag. (Price DM. 58.00).

NEEDHAM, JOSEPH. "*The Development of Iron and Steel Technology in China*." 9¾ × 7½ in., pp. xii + 76 [+ 31 plates]. Illustrated. London, 1958: The Newcomen Society. (Price 35*s*.).

SCHAARWÄCHTER, CARL UND WERNER SCHAARWÄCHTER. "*Verfahren zur Oberflächensilizierung für Stahlbleche und-bänder durch Reduktion Siliziumtetrachlorid in Lichtbogen und Versuche über die Reduktion von Titantetrachlorid*." (Forschungsberichte des Wirtschafts-und Verkehrsministeriums Nordrhein-Westfalen. Nr. 297). 4to, pp. 22. Illustrated. Köln und Opladen, 1958: Westdeutscher Verlag. (Price DM. 8.20).

SCHEER, LEOPOLD. "*Was ist Stahl? Eine Stahlkunde für jedermann*." (11 erw. Aufl.). 8vo., pp. viii + 127. Illustrated. Berlin, 1958: Springer-Verlag. (Price DM. 7.50).

SCHORSCH, HERBERT. "*Gütebestimmung an technischen Oberflächen Normen. Prüfverfahren und Prüfgeräte, Arbeits-und Auswertehinweise*." (Optik und Feinmechanik in Einzeldarstellungen Bd. 1). 8vo, pp. xii + 186. Illustrated. Stuttgart, 1958. Wissenschaftlichts Verlagsgesellschaft. (Price DM. 28.50).

SCHUMANN, EDGARD (Editor). "*Das Buch vom Rost. Fe_2O_3, H_2O. Entstehen, Verhüten, Bekämpfen*." (Markt & Technik Band 1). 8vo, pp. 304. Illustrated. Wiesbaden, 1958: Industrie-Verlag. (Price DM. 18.50).

"*Scientific and Academic Life in Western Germany. A Handbook*." 8 × 6 in., pp. 183. Illustrated. Essen, 1957: Stifterverband für die Deutsche Wissenschafts.

SMOTHERS, W. J., and Y. CHIANG. "*Differential Thermal Analysis: Theory and Practice*." 9½ × 5½ in., pp. 444. Illustrated. New York, 1958: Chemical Publishing Co. Inc. (Price $16.00).

"*Statistisches Jahrbuch für die Eisen-und Stahlindustrie* 1957/58." (Wirtschaftsvereinigung Eisen-und Stahlindustrie). 8vo, pp. x + 273. Düsseldorf, 1958: Verlag Stahleisen. (Price DM. 10.00).

VOGT, E. "*Physikalische Eigenschaften der Metalle*." Band 1. Metallektronentheorie, Thermisch-Elastisches Verhalten, Magnetismus. 9½ × 6¼ in., pp. xii + 467. Illustrated. Leipzig, 1958: Akademische Verlagsgesellschaft Geest & Portig K.-G. (Price DM. 59.00).

WEVER, FRANZ, WILHELM WINK AND WERNER JELLINGHAUS. "*Suszeptibilitätsmessungen an hochwarmfesten Legierungen auf Nickel–Chrom–und Kobalt–Nickel–Chrom–Grundlage*." (Forschungsberichte des Wirtschafts-und Verkehrsministeriums Nordrhein-Westfalen Nr 597). 4to, pp. 33. Illustrated. Köln und Opladen, 1958: Westdeutscher-Verlag. (Price DM. 12.00).

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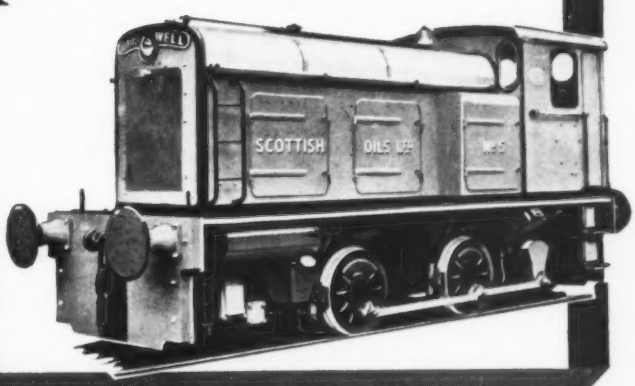

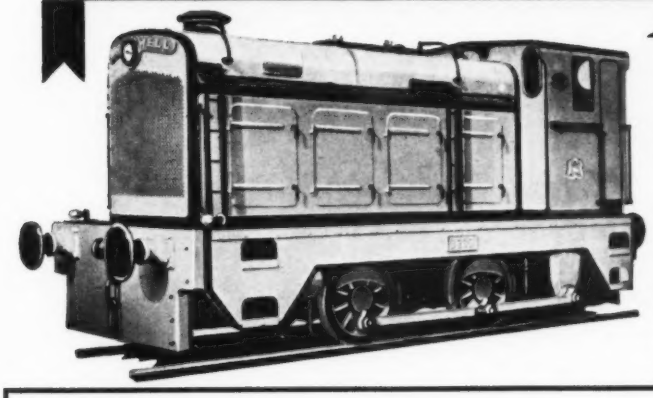

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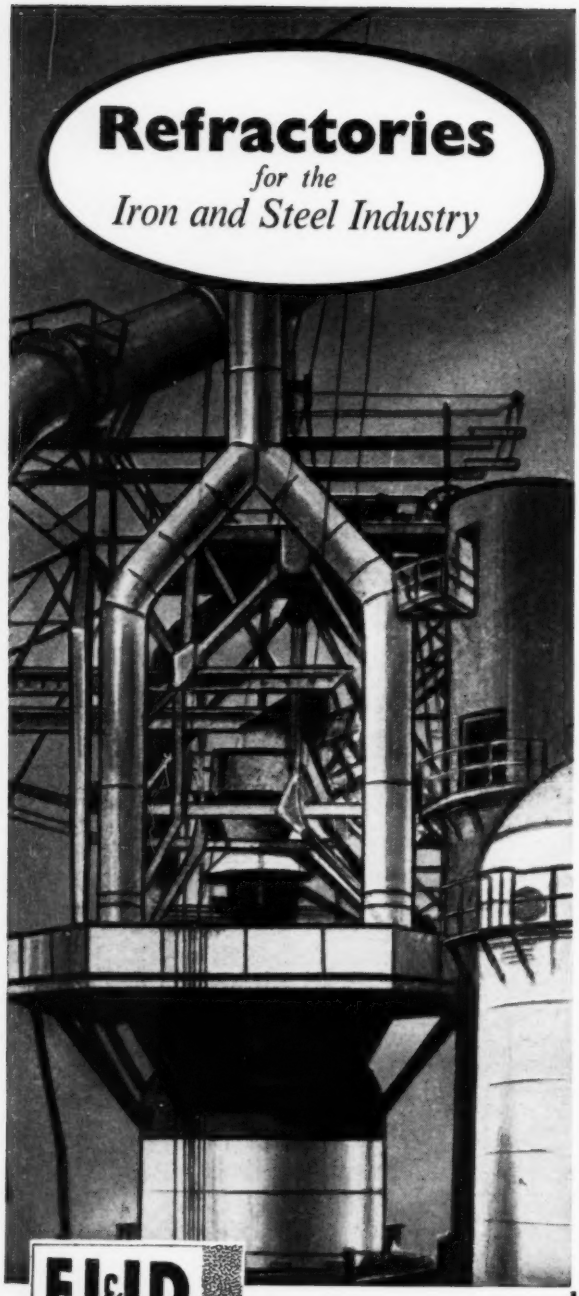

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The first edition of this survey appeared in 1951 as No. 44 in The Iron and Steel Institute's Special Report Series, and was quickly sold out. In view of the many requests for copies of what is now a standard work of reference, it was decided to issue a second edition, with some important additional material. Through the courtesy of Richard Thomas and Baldwins Ltd., The Steel Company of Wales Ltd., and John Summers and Sons Ltd., the Sub-committee has been able to include an addendum devoted to surface defects in steel strip products.

The second edition is now available as **Special Report No. 63;** it consists of 62 quarto pages, illustrated with 134 excellent photographs of surface defects, and bound in cloth with stiff board covers. The Report costs £1 5*s*. 0*d*. (15*s*. 0*d*. to Members), and may be obtained on application to

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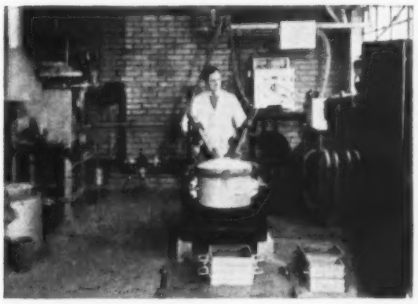

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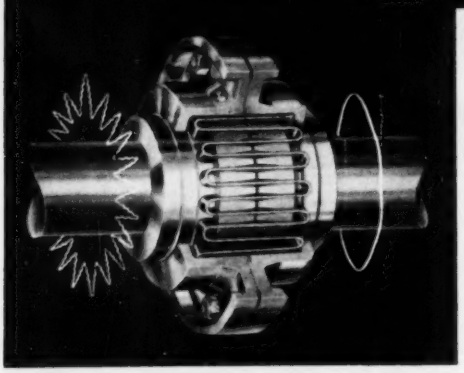

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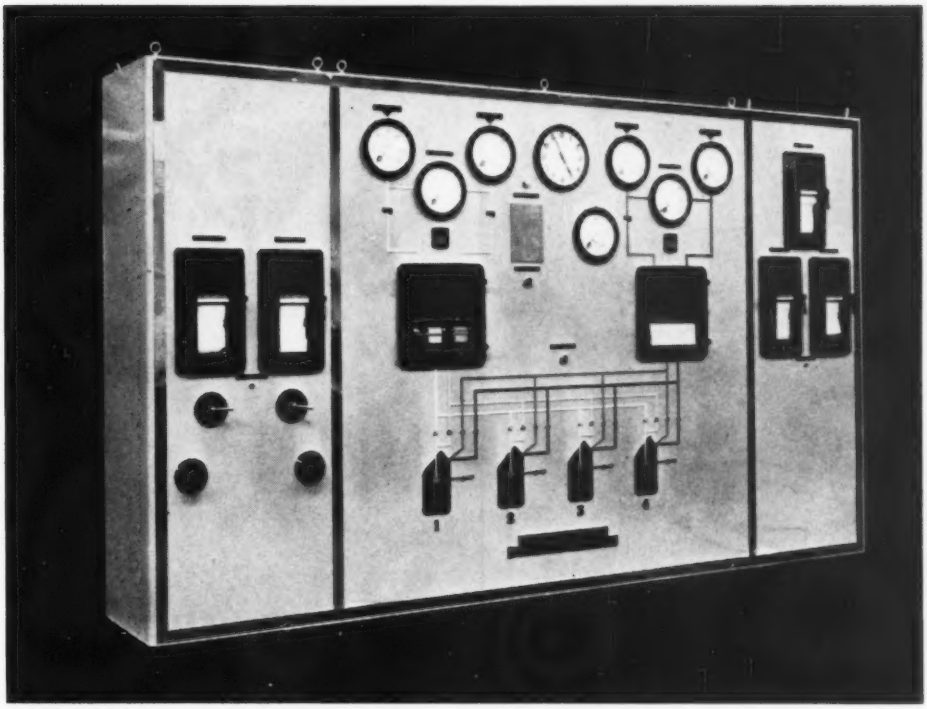

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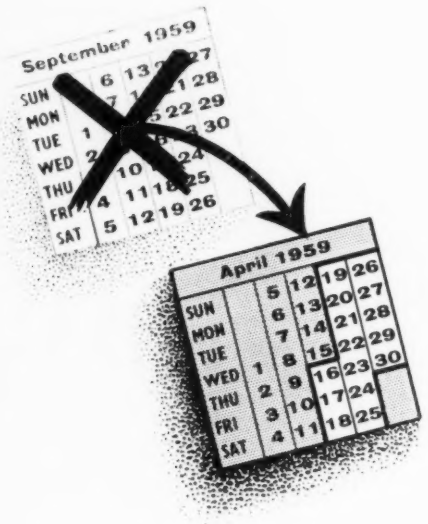

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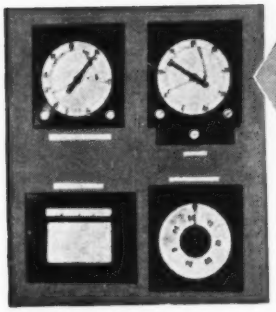

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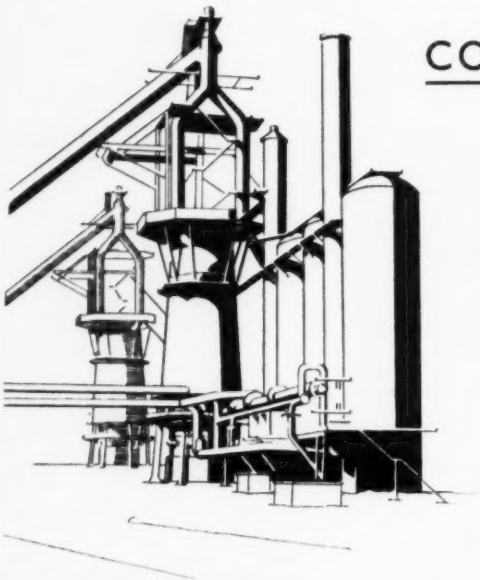
ON 25th-26th September and on 11th-12th December, 1957, in anticipation of the Clean Air Act, 1956 and the Rivers (Prevention of Pollution) Act, 1951 coming into full effect in June and August, 1958 respectively, the Iron and Steel Engineers Group of the Institute held two meetings on Air Pollution and Water Pollution in the Iron and Steel Industry.

Twenty-five papers were written especially for the meetings, by authors from Austria, France, Germany, the U.S.A. and the U.K. During the meetings some lively and informative discussions took place, in which experts in a variety of fields gave their views. The papers, the reports of the discussions, and contributions received subsequently to the meetings, together with additional authors' replies, have now been published as a Special Report in one volume of 260 pp.

The report, No. 61 in the Special Report series of the Institute, is illustrated with over 200 diagrams and photographs and is bound in cloth with stiff board covers. Copies can be obtained from the offices of the Institute, 4 Grosvenor Gardens, London S.W.1, price £4 5s. 0d. (Members £4 5s. 0d.)



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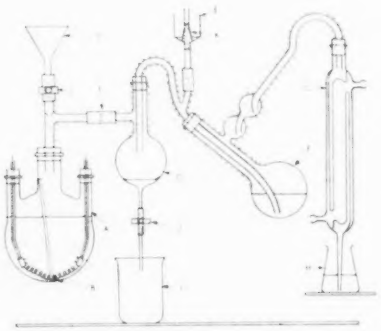

Great interest has always been shown in the role of nitrogen in determining the properties of ferrous alloys. Reliable and accurate methods are therefore necessary for determining the content of this element in alloys.

The establishment of the reproducibility and accuracy of analytical methods to serve as routine or reference procedures for the many alloys now produced is a major undertaking. It was for this reason that the Nitrogen Group of the Steelmaking Division of the British Iron and Steel Research Association was set up eight years ago. The Report of the Group has now been published as No. 62 in The Iron and Steel Institute's Special Report Series. The information it contains will be of inestimable value to all those interested in this subject.

The Report, which comprises 160 quarto pages and a number of illustrations, is bound in cloth with stiff covers, and costs £1 17*s.* 6*d.* (Members £1 5*s.* 0*d.*). It may be obtained from:—

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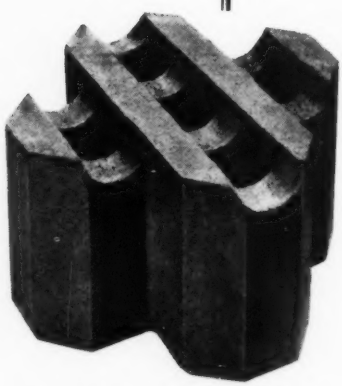

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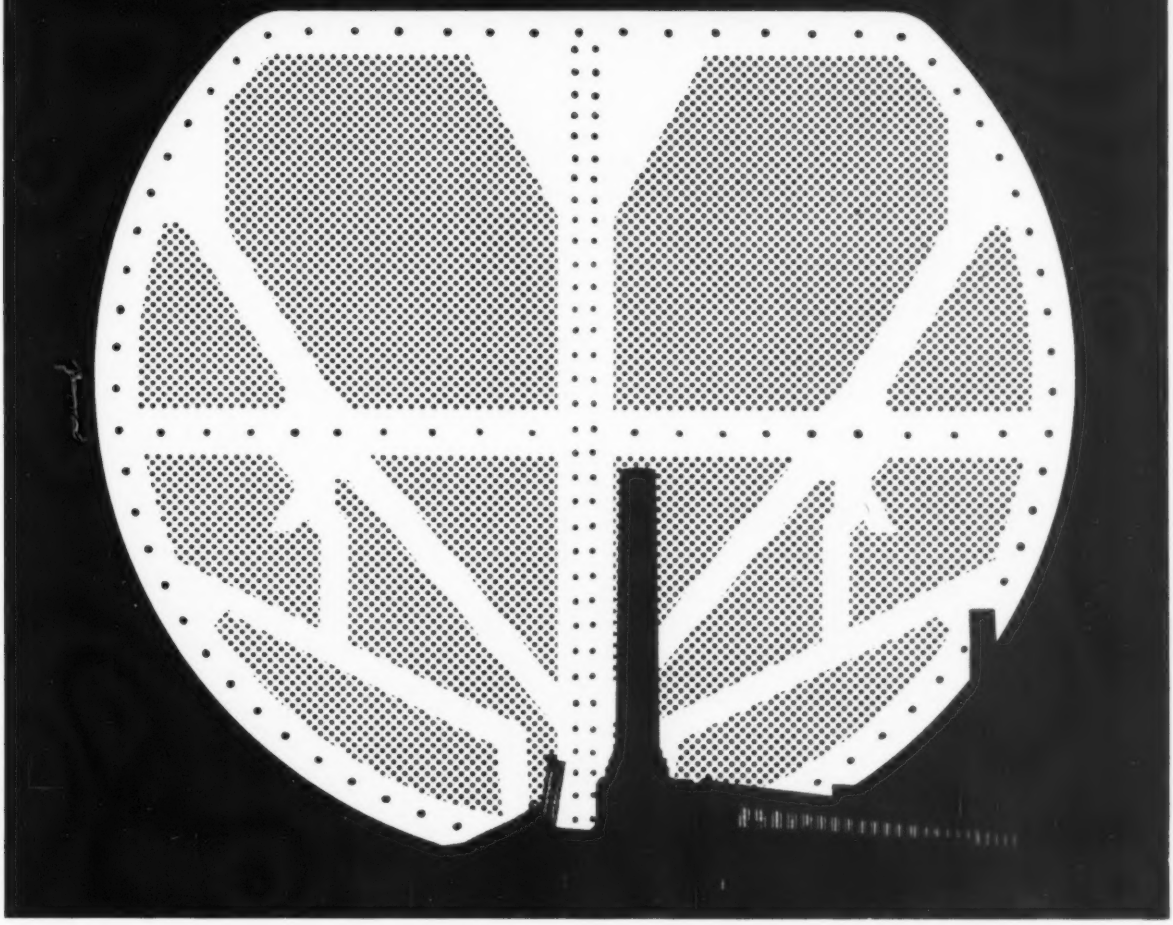

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Published at the offices of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, and Printed in Great Britain by HARRISON & SONS, LTD., by Appointment to Her Majesty The Queen, Printers, London, Hayes (Middx.) and High Wycombe.

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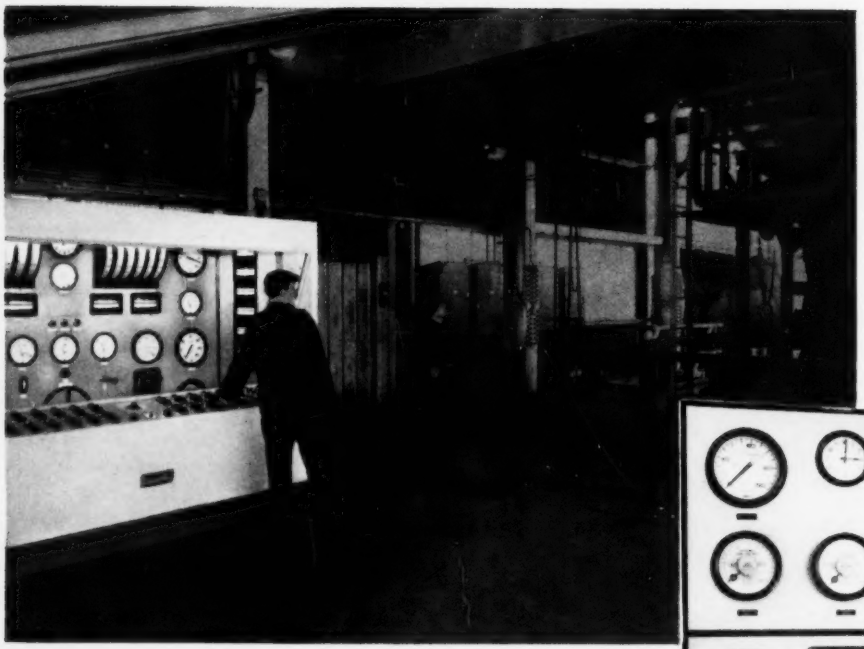

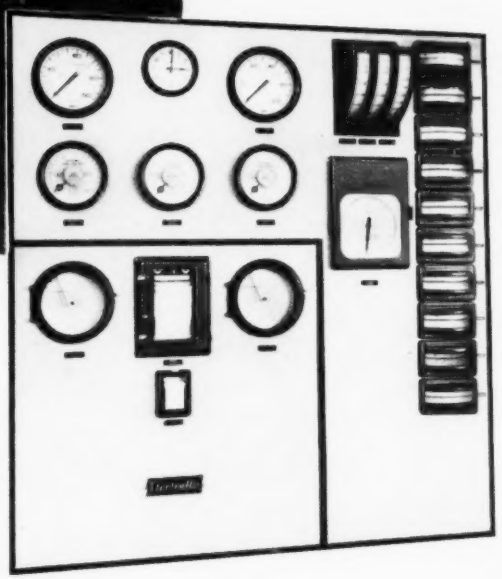

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